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# Recovery of memory after severe closed head injury as measured by the selective reminding procedure.

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RECOVERY OF MEMORY AFTER SEVERE CLOSED HEAD INJURY  
AS MEASURED BY THE SELECTIVE REMINDING PROCEDURE

by

Christopher E. Paniak

B. A. University of Alberta, 1985

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A Thesis

Submitted to the Faculty of Graduate Studies  
through the Department of Psychology  
in Partial Fulfillment of the  
Requirements for the Degree  
of Master of Arts at the  
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1987

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## ABSTRACT

This study examined selective reminding and recognition memory performance of 21 severely closed head injured patients tested within 6 months of regaining consciousness and then at least once again after one year. In addition, length of coma (LOC) was compared to Average Impairment Rating (AIR) as a predictor of long-term memory outcome. Patients performed worse than hospitalized age, education, and sex-matched controls at first testing on all selective reminding and recognition memory parameters. Statistically significant improvement between first and second testing was seen on only 4 of 6 memory parameters. Five of the 21 patients were tested a third time and a linear improvement across all three testings was found on 3 of 4 of the parameters that improved across two testings for the overall patient group. AIR score at first testing and length of coma were both inversely related to memory function at second testing, but both had roughly the same predictive validity. Implications of these findings were discussed in terms of (a) dissociations in recovery of memory processes and their relationships to the often inattentive and anergic information processing style(s) of severely closed head injured patients and (b) the utility of psychometrically and physiologically based measures of injury severity to predict memory outcome.

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## CHAPTER I

### INTRODUCTION

Head injury is among the most common causes of disability, especially among young adults. Estimates of the incidence of head injury range from 170 to 600 cases per 100,000 per year, depending on inclusion criteria (Levin, Benton, & Grossman, 1982). Although physical disability is often the most apparent consequence of head injury, recent studies have found that cognitive and emotional problems are more socially and vocationally disabling (Bond, 1975).

The most commonly reported of the ~~cognitive problems~~ after head injury is impairment of memory function (Levin et al., 1982; Van Zomeren, 1981, p. 9). Quantification of memory deficit with neuropsychologic assessment is an important first step toward adequate management of this deficit. Repeated memory testing, in turn, allows for the determination of the natural course of recovery, and potentially allows prediction of outcome based on measurements collected early in recovery. Adequate delineation of the natural course of recovery in head injury patients also allows one to evaluate the success of rehabilitation efforts.

The literature review which follows is divided into four main sections. The first section is a brief review of contemporary

models of memory. The second section presents some of the pathophysiology associated with head injury and its relationship to memory dysfunction. The third section reviews two commonly used clinical memory assessment measures. These are the Wechsler Memory Scale and the selective reminding procedure, developed by Herman Buschke. The utility of each of these measures in the assessment of memory after head injury is examined. The final section consists of a review of studies that have used the selective reminding technique to assess memory function after head injury.

#### Models of Memory

Memory, in the simplest sense, refers to the ability to maintain information over time (Lachman, Lachman, & Butterfield, 1979). Models of memory in current use are (a) multistore models and (b) memory as one component of an information processing system (Baddeley, 1976).

Multistore models of memory generally assume that memory is composed of three stores or components. These three stores are: (a) a sensory register, (b) a short-term store, and (c) a long-term store. The sensory register is said to contain an evanescent, but nearly complete record of the sensory image. The purpose of the sensory register is to hold information momentarily until selected input can be brought into the next stage of memory,

short-term memory. Short-term memory is referred to as active memory where information is transferred from the sensory register and/or long-term memory, and subjected to conscious mental or cognitive processes. A relatively common research finding in the past was that short-term memory had a very circumscribed capacity, essentially limited to  $7 \pm 2$  chunks (Miller, 1956). Each chunk contains one or more items of information. The more meaningful and related items are, the greater the number of them that can be grouped into one chunk (Anderson, 1985). Information is posited to be maintained in short-term memory by rehearsal or other active processes, until it is displaced by other information, lost due to inattention, or possibly transferred into long-term memory. Long-term memory is said to be a durable and semantically based store of almost unlimited capacity (Baddeley, 1976). Information can pass into long-term storage from short-term storage either intentionally or incidentally. Information that is not used is said to eventually decay and be lost from long-term memory. Alternatively, information could be lost due to disruption from new inputs that changes the form of the old information (Lachman et al., 1979, p. 223).

The explanatory power of multistore models is greatest when applied to list-learning paradigms. For example, when a subject is asked to recall a list of several words just presented, recall is usually found to be greatest for words at the beginning and at the end of the list (Glanzer & Cupitz, 1966). Words at the

4

beginning of the list are said to be necessarily recalled from long-term storage. This is because incoming information impairs the rehearsal processes necessary to maintain words in the short-term store. Words from the beginning of the list are more readily transferred into long-term storage than are words from the middle of the list because incoming information has not yet overloaded short-term memory in the case of the former words (Parker & Serats, 1976). Words at the end of the list are said to be recalled because they are not displaced by subsequent incoming information. This allows for their rehearsal and maintenance in short-term memory (Parker & Serats, 1976). The robust phenomena of better recall for earliest and most recently presented words have become known as primacy and recency effects, respectively.

Although multistore models have considerable heuristic value, dissatisfaction with structural multistore models grew as more sophisticated experiments called into question certain characteristics of these models. For example it was found that the duration of time information spent in the sensory register was largely a function of experimental parameters, such that information could exist in the sensory register for as long as information did in short-term memory (Lachman et al., 1979, p. 267). Difficulty in distinguishing between memory stores was not the only problem encountered. A more telling criticism of multistore models was that although they explained the results of list learning experiments adequately, they faltered when

explanations of memory for complex, real-life events were required. The complex network of associations found to be at the core of natural, pragmatic memory are not easily explained by the rather rigid multistore models (Lachman et al., 1979, p. 269).

A more recent conceptualization of memory that more adequately accounts for phenomena outside of the list-learning paradigm is summarized by Anderson (1985). This model may be referred to as a functional rather than a structural approach to memory (Baddeley, 1976), although structure is certainly not disregarded. Indeed, the concepts of a sensory store, a short-term store, and a long-term store are retained in modified forms. The sensory store is retained, although it is deemphasized in the functional view of memory. Short-term memory (working memory) is still viewed as a limited capacity store in which information is actively processed. Finally, long-term memory is retained as a large-capacity storehouse of information. The difference between structural and functional conceptualizations of memory lies more in the processes relating short-term and long-term memory to each other and the mechanisms by which memory operates.

A fundamental difference between functional and structural approaches to memory is that the former largely views working memory as long-term memory in an activated state, rather than a structural unit unto itself. The active information processing that characterizes working or short-term memory is held to



simultaneously strengthen the associations between materials already in long-term memory and whatever new input is being considered. The "depth" or thoroughness with which information is processed ( Craik & Lockhart, 1972) is strongly related to later recall of the information (Bobrow & Bower, 1969; Smith, 1977). Information is said to be more deeply or elaboratively processed when it is linked to related data in memory. This process of association builds up knowledge structures such that related material is connected by stronger links than is unrelated material. To provide a simple example, the item dog has a stronger association with the item bone than dog does to the item taxicab. The concept of differing strengths of such links and pathways has been validated in reaction-time/memory paradigms (Meyer & Schvaneveldt, 1971; Perlmutter & Anderson, in Anderson, 1985).

Associations between items in long-term memory are strengthened by elaborations performed by working memory. Individuals elaborate on information by relating it to other knowledge, by thinking and inferring about the information, and by associating it with features from the current context. This information processing improves memory by providing alternate pathways through which information is recalled, by imposing an organization on material that guides retrieval, and by possibly increasing the contextual commonalities between the learning and recall occasions (Anderson, 1985).

It is interesting to note that if cognitive processing is controlled for, intention to remember may become relatively unimportant in memory performance (Bobrow & Bower, 1969; Hyde & Jenkins, 1973; Nelson, 1976). That is, if an individual actively attends to, and performs cognitive operations on information but does not know recall will be required, recall will often be as accurate as for a subject who performs the same elaboration processes but who is also aware that retrieval will be required. In natural settings where elaboration or cognitive processing is not controlled for, however, those who know retrieval will be required are generally more likely to engage in elaboration. This will usually lead to better memory.

It is widely accepted that bits of information that are joined by strong associations are more likely to be recalled together than information that is weakly associated (Anderson, 1985). Impairment in memory can often be traced back to deficits in the processes executed by working memory, collectively known as encoding processes. In the present conceptualization, retrieval is dependent on the adequacy of encoding (Buschke, 1974a). In the extreme, if information is not attended to, no encoding occurs. If the information is in working memory but only inefficient processing such as repetition is conducted, memory for the relevant information will be reduced relative to a condition where elaboration on the information is conducted (Bobrow and Bower, 1969). A relatively passive approach to cognitive processing

which involves awareness of, but little elaboration on or thought about the material to be remembered has been implicated in memory deficits associated with aging (Buschke, 1984). Failure to effortfully process and elaborate on information as well as diminution of cognitive resources may also be implicated in memory deficits associated with head injury (Mattis & Kover, 1984). These will be discussed in a subsequent section of this paper.

In conclusion, memory is typically conceptualized in terms of a three store structural model and/or a functional model that incorporates structural components. Elucidation of memory processes, as offered especially by the functional approach, has led to a more thorough understanding of normal memory. This, in turn, allows one to more clearly understand the nature of deficient memory, as often results after head injury

#### Pathophysiology of Head Injury and Memory Effects

This section consists of three parts. First, a brief review of the mechanisms and pathophysiology of closed head injury is presented. This review is not comprehensive but rather has a selective focus. Those mechanisms and pathologies associated with memory impairment receive primary emphasis. The second subsection is a brief review of some indicators that are used to gauge the severity of head injury. In the third part of this section, the types of memory impairment associated with the pathologies discussed in part one are presented.

Pathophysiology. The two major types of head injury differentiated in the literature are open and closed head injury (Levin et al., 1982). Open head injury occurs when the dura mater is penetrated. This is most often the result of a gunshot wound, although other mechanisms are possible. Closed head injury is an injury in which the meninges are not penetrated (Gilroy & Holliday, 1982). A closed head injury may be classified as either an acceleration or a deceleration injury (Reitan & Wolfson, 1985a). An acceleration injury occurs when a fast moving object strikes a stationary head. A blow to the head with a blunt instrument is one example of an acceleration injury. A deceleration injury occurs when a moving head hits a stationary object. A head striking the windshield of a car that has come to a sudden stop is an example of a deceleration injury. Although both forms of closed head injury may, in some cases, lead to very similar damage, deceleration injuries, such as those associated with automobile accidents, often lead to more widespread damage (Levin et al., 1982).

Levin et al. (1982) outlined the specific types of brain damage that may result after closed head injury. Primary effects are those types of damage that occur on impact. They include macroscopic lesions such as coup and contrecoup contusions, as well as microscopic lesions such as the extensive stretching and shearing of nerve fibres (Adams, Mitchell, Graham, & Doyle, 1977). Secondary mechanisms, which may shortly follow primary effects,

include intracranial hemorrhage, edema, ischemia, and increased intracranial pressure (Adams et al., 1977). Finally, delayed effects such as white matter degradation and disruptions of cerebrospinal fluid flow (hydrocephalus) may cause impairment. Primary and secondary mechanisms are now considered in greater detail.

Primary effects of closed head injury are those which occur on impact. In non-trivial head injury the skull is temporarily bent inward and the brain rotates inside the skull because of the force of the blow. Coup contusion (bruising) results from the force at the area of impact. Contrecoup contusion describes distal damage that results when rotational acceleration forces cause the brain to glide in its dural component (Van Zomeren, 1979). Coup damage may occur after a blow anywhere on the head. On the other hand, contrecoup lesions are far less likely to occur in occipital than in fronto-temporal areas. This is because the skull cavity is relatively smooth in the posterior fossa whereas the anterior and middle fossae have many bony protuberances. In addition, the tissue in the fronto-temporal areas is of varied density; this makes it more susceptible to contusion when the force of the blow displaces tissue (Omay & Gennarelli, 1974). Contusions do not only affect the cerebral hemispheres; the brainstem is also often affected (Adams et al., 1977).

Of the primary effects of closed head injury, however, coup and contrecoup contusion are not the most pervasive. Rather, the

stretching and shearing of nerve fibres upon impact appear to be the most common primary effects (Strich, 1961). In the preponderance of cases, contusive injuries are superimposed on this diffuse fibre damage. Rotation of the brain and brainstem after a forceful blow to the head has been implicated as the primary mechanism in the diffuse shearing of fibres (Strich, 1961). The frontal and temporal lobes are especially susceptible to this type of fibre damage, due to the bony irregularities of the anterior and middle cranial fossae and variation in tissue density in these areas (Ommaya & Gennarelli, 1974).

Stretching and shearing of brainstem reticular fibres and structures are assumed to be the immediate causes of loss of consciousness (Gurdjian, 1975, pp. 215-216). However, such damage rarely occurs without concomitant fibrous damage to the cerebral hemispheres (Ommaya & Gennarelli, 1974). The realization that this widespread stretching and shearing of nerve fibres is extremely common after closed head injury has come about only after microscopic post-mortem examinations of the brain (Adams et al., 1977; Oppenheimer, 1968; Strich, 1961). CT scans do not detect such microscopic damage although new generation scanners such as magnetic resonance imagers appear to be more sensitive to such lesions (Levin, Kalisky, Handel, Goldman, Eisenberg, Morrison & Laufen, 1985).

Secondary effects of head injury are those which result from the physiological processes occurring after primary injury.

Hematoma, be it intracerebral, subarachnoid, subdural, or epidural, is the primary cause of focal secondary damage (Levin et al., 1982). Hematoma arises as a result of blood vessels being torn. Depending on the location of the collection of blood, damage may be the result of direct contact of blood with brain tissue or due to pressure effects of the expanding mass, or both. Adherence of clotted blood to arteries in the subarachnoid space may lead to vasospasm and subsequent ischemic damage (Kassell, Boarini, & Adams, 1982). Cerebral edema, which may produce focal or diffuse effects depending on its pervasiveness, is often found in the area of hemorrhages and contusions (Strich, 1969). Edema contributes to expanding mass effects, but it is unclear whether edema damages the brain directly (Levin et al., 1982). It is interesting to note that, as with primary damage, hemorrhages and consequent edema occur disproportionately in fronto-temporal areas.

Increased intracranial pressure is often associated with intracranial hematoma and edema (Strich, 1969). The increase in intracranial pressure reduces cerebral perfusion pressure, which in turn reduces blood flow (Marshall & Bowers, 1982). Diffuse ischemic damage may eventuate as a result of these mechanisms (Levin et al., 1982). The hippocampus and basal ganglia may be particularly susceptible to such ischemia, especially with severe injury (Van Zomeren, 1981).

In summary, this brief description of the mechanisms and pathophysiology associated with closed head injury presents several issues relevant to the researcher of memory disorder. Tissue damage associated with head injury is rarely only of a focal nature. Rather, focal lesions such as contusion and hematoma are usually superimposed on widespread microscopic white matter damage. To the extent that focal lesions do occur, however, they are likely to be in the temporal and orbito-frontal areas. This is due to the structural irregularities of the anterior and middle cranial fossae. Ischemic damage, although often widespread, may especially affect areas such as the hippocampus (located in the temporal lobe). Possible delayed effects (not elaborated upon here) such as hydrocephalus and degeneration of cerebral white matter may also combine and interact with aforementioned pathophysiology to produce a variety of outcomes. In a word, however, widespread or diffuse damage with the possibility of more severe focal lesions in the fronto-temporal areas is most characteristic of the pathophysiology of non-trivial closed head injury.

Measures of head injury severity. There are three commonly reported measures of the severity of head injury. These are (a) length of coma, (b) Glasgow Coma Scale score, and (c) duration of post-traumatic amnesia.

Length of coma has been variously defined in the literature. Depending on the investigator, termination of coma has been said



to occur anytime from the onset of eye opening (Jennett & Teasdale, 1981) to onset of the ability to establish intellectual contact with the environment (Stover & Zeiger, 1976). Regardless of the validity of any particular measure of coma duration, the lack of reliability across observers and the lack of consistency in definition across studies often makes research findings difficult to compare. Other problems with the use of coma duration as a measure of severity are that (a) coma has many gradations, making simple classification almost impossible (Stover & Zeiger, 1976) and (b) many patients are maintained in coma for medical reasons by the administration of barbiturates. Duration of coma as a measure of severity of injury is relatively meaningless in such cases.

Largely in response to the unreliability of coma assessment by different observers, the Glasgow Coma Scale (GCS) was developed (Jennett & Teasdale, 1981). The GCS consists of three subscales: (a) eye opening, (b) best motor response, and (c) best verbal response. Responses are scored on four, six, and five point scales, respectively. A score of one point on each scale, for a total of three points, is the most impaired score obtainable whereas a total summed score of 15 is indicative of optimal function. Standard instructions are used so as to maximize reliability across observers. The Glasgow Coma Scale has gained wide acceptance as a measure of injury severity (Myers, Levin, Eisenberg, & Guinto, 1983; Tabaddor, Mattis, & Zazula, 1984).

However, induction of barbiturate coma, existence of peripheral injuries, and language deficits are but three factors which may limit the utility of the Glasgow Coma Scale as a measure of injury severity.

Duration of post-traumatic amnesia (PTA) has also been used as an indicator of the severity of head injury. Post-traumatic amnesia is said to have ceased when continuous anterograde memory for events has returned (Russell, 1932). Specifically, Russell's original formulation defined PTA as the time from injury to the time at which the patient recalled having continuous anterograde memory. Such a definition may produce notoriously unreliable and invalid data because of personal biases and a host of other / contaminating variables (Stover & Zeiger, 1976). An alternate method to assess PTA involves the daily questioning of the patient for events in the patient's environment. This strategy has the potential to be more reliable and valid than Russell's procedure. It is nevertheless subject to variability dependent on such factors as the extent of questioning. Results may also be affected by conditions that affect the patient's responses (e.g. aphasia), but that are independent of memory function, per se.

It is apparent that the three most commonly used measures of severity of head injury each have their limitations.

Nevertheless, a classification system that Russell (1932) proposed and that Jennett and Teasdale (1981) expanded upon has become a commonly used index of injury severity. The classification is

based on duration of PTA or time from injury to return of continuous anterograde memory. It is as follows:

Very mild: less than 5 minutes  
Mild: 5 to 60 minutes  
Moderate: 1 to 24 hours  
Severe: 1 to 7 days  
Very severe: 1 to 4 weeks  
Extremely severe: more than 4 weeks

Although length of coma, Glasgow Coma Scale scores, and length of PTA are three of the most commonly used indicators of severity of injury, other indicators have also been used to assess functioning after head injury. These include neuropsychological indexes such as the Halstead Impairment Index (HII) and the Average Impairment Rating. The HII (cf. Halstead, 1947) is actually a consistency-of-impairment index that is derived from a patient's performance on 10 neuropsychological tests found to discriminate between groups of normal and brain damaged subjects. Based on cutoff points, performance on each test is classified as indicative or nonindicative of brain damage. A performance in the brain damaged range on any given test adds .1 to the index. The most impaired HII score possible is 1.0, based on impaired performance on all tests. A HII score of .5 or greater or greater is considered indicative of brain damage. The HII has subsequently been modified by Reitan (Reitan & Wolfson, 1985b) to include only the seven tests shown to most reliably discriminate between groups of brain damaged and nonbrain damaged subjects.

The Average Impairment Rating (AIR) was developed by Rennick (Russell, Neuringer, & Goldstein, 1970). The AIR for a patient's performance is derived from many of the same tests used to derive the HII, plus some additional measures. Other than including some additional neuropsychological measures, the major difference between the HII and the AIR is that the latter classifies performance on each test into one of five grades (zero to four). A score of zero is assigned if performance is more than one standard deviation above the mean of a normal control group and a score of one is assigned if performance is within the range of plus or minus one standard deviation of the control group. Performances more than one, two, or three standard deviations below the mean of the control group are assigned scores of two, three, and four, respectively. The overall AIR is then obtained by finding the average of the AIR scores across relevant measures. The major advantage of the AIR is that it allows evaluation of the degree of severity of brain damage, rather than only classification into a simple dichotomy of brain-damaged versus nonbrain damaged performance (Russell et al., 1970).

In conclusion, the AIR has several advantages over more conventional indices of injury severity such as length of coma, Glasgow Coma Scale scores, and duration of PTA. One advantage is that the AIR represents a finer grained, quantified assessment of the degree of impairment present in skills necessary for daily functioning. Also, because the AIR is obtained after the return

of consciousness, factors such as barbiturate coma that render other measures meaningless are not contaminants. The more conventional indices of severity of injury are much cruder measures of skills necessary for daily functioning, if they can be considered that at all. Rather, the more conventional measures may be good indicators of low-level level functioning in a patient who is in coma or has recently emerged from coma. The value of conventional measures is very limited once a patient has progressed beyond a grossly impaired state.

Pathophysiology and memory. It was stated in a previous subsection that diffuse, microscopic white matter damage is the predominant pathology following head injury. The frontal and temporal lobes were said to be especially susceptible to such microscopic damage, as well as to macroscopic focal lesions. In this subsection, discussion will initially focus on brain structures traditionally associated with memory function that may be affected by head injury. These are the temporal lobes and the diencephalon. Then the frontal cortex and cerebral cortex as a whole are considered in terms of their associations with memory deficiency after head injury.

The temporal lobes, it will be recalled, are susceptible to microscopic white matter lesions, macroscopic lesions, and damage due to ischemic processes after head injury. It has also been accepted for many years that the temporal lobes, especially mesial temporal structures such as the hippocampus, are associated with

memory function in man (Halgren, 1984). Left and right temporal lobe lesions have been shown to affect memory for verbal and visuospatial materials, respectively (Butters & Miliotis, 1985; Mayes & Meudall, 1984). Since this paper deals with memory for verbally presented materials only, the implicit assumption from this point forward is that the left temporal lobe is of primary concern when discussion of temporal lobe function and memory is presented.

Traditionally, temporal lobe damage had been associated with disruption of the consolidation of materials presented. In other words, patients with temporal lobe excisions were found to be able to maintain information in short-term (working) memory as long as rehearsal was allowed (Butters & Miliotis, 1985). With interference or after a delay during which rehearsal was prevented, however, memory for the relevant material was severely impaired. This was assumed to be because the information had not been consolidated, or transferred into long-term memory (Winocur, 1984). More recent formulations of the role of the temporal lobe in memory performance, however, have been more in line with a functional rather than a structural approach to memory. From the functional perspective, the medial temporal lobe is crucially involved in the formation of associations between to-be-remembered materials (Winocur, 1984). The storage of information is purportedly distributed throughout the brain; the temporal lobe's role is to build knowledge structures through the elaboration of

connections between items in memory. With severe temporal lobe damage, the formation of such knowledge structures in long-term memory is assumed to be impaired.

Diencephalic structures such as the thalamus, which may be damaged with closed head injury, have been the other most investigated brain ~~area~~ with regard to memory functions. Patients with diencephalic lesions have often been found to learn at very slow rates but to forget at relatively normal rates (Mayes & Meudall, 1984; Winocur, 1984). This is in contrast to patients with temporal lobe lesions who forget abnormally fast, due to their postulated deficit in building knowledge structures for the facilitation of later recall.

The frontal lobes are at disproportionate risk for damage by closed head injury. Functions vital for memory performance which are purportedly subserved by this area of the brain have been the subject of much recent investigation. These functions necessary for memory have generally been referred to as cognitive processing skills (Mayes & Meudall, 1984). These skills are similar to those proposed to be subserved by the temporal lobes. Cognitive processing skills are those effortful processes that organize to-be-remembered material, or relate it to previously known information in order that later recall may be facilitated.

Buschke (1984) has proposed that deficient memory can be imputed as the reason for recall failure only when cognitive processing has been controlled for. In other words, if one uses

processes that have been found to improve memory, yet recall remains impaired, then and only then can memory be considered impaired. Buschke thus contends that cognitive processing deficits are the cause of many so-called memory deficits. In this vein, it has been found that in a variety of subjects, including some with head injury (Mattis & Kovner, 1984) that externally provided and demanded mnemonic strategies may improve recall ability greatly. From these results it has been inferred that the lack of spontaneous initiation of mnemonic processes (such as relational operations) is characteristic of many patients with memory deficits (Cermak, 1984; Mattis & Kovner, 1984). Rather than the active operations carried out spontaneously or effortfully to enable later recall, patients with memory deficits seem to passively experience stimuli without actively relating them to other to-be-remembered material, or using other effortful processes. This in turn is hypothesized to inhibit chunking processes (Buschke, 1984) and/or prevent the stimuli from gaining sufficient distinctiveness to be differentiated from other materials in the long-term store (McDowall, 1984).

The final type of pathology to be related to memory impairment in the present context is the diffuse microscopic shearing and stretching of nerve fibres. Such distortion of neural fibres often extends to structures of the brainstem reticular formation. Even though such distortions have commonly been referred to as the primary mechanism in inducing coma,

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disruption of the reticular activating system may also lead to hypoarousal when the patient is conscious. Such hypoarousal may be associated with decreased speed on information processing (Van Zomeran, 1981) commonly found after non-trivial head injury. This global decrease in information processing speed may, in part, account for memory difficulties found in patients with no evidence of macroscopic damage to left temporal or frontal areas (Levin, Kalisky, Handel, Goldman, Eisenberg, Morrison, & Laufen, 1985).

In conclusion, it is apparent that deficits in any of a variety of skills purportedly subserved by various brain areas may affect the ability of an individual to recall information at a later time. Although there has been some success achieved in terms of relating particular memory deficiencies to lesions in various areas of the brain, much work remains to be done. To the extent that such relationships do exist, they are often obfuscated in head injured patients. This because such patients almost inevitably have widespread, microscopic damage of brain substance in addition to any macroscopic lesions that may be present.

#### Two Memory Assessment Techniques Used to Study Head Injury

##### Sequelae

This section consists of two parts. The first subsection critically assesses the ability of the most-used clinical memory assessment device, the Wechsler Memory Scale, to elucidate the extent and nature of memory impairment after head injury. The

primary advantages and disadvantages of the Scale are summarized. In the second subsection, the selective reminding procedure is explicated and is presented as an attractive alternative to the Wechsler Memory Scale for the assessment of memory impairment after head injury.

The WMS and head injury The WMS was introduced by Wechsler (1945) as an expeditious and simple, yet practical test of memory. It consists of seven subtests: Personal and Current Information, Orientation, Mental Control, Logical Memory, Memory Span, Visual Reproduction, and Associate Learning. Procedures supplied enable the user to correct test performance for age and to obtain an overall index of performance, the memory quotient (MQ). Until recently, the test had had a virtual monopoly in the area of clinical memory testing (Erickson & Scott, 1977). This was the case despite the fact that the scale suffered several serious shortcomings. Some of these shortcomings, as well as potential uses, for the WMS in an head injured population are considered here.

An initial criticism of the WMS is that the overall scoring statistic (the MQ) is inadequate because it masks potentially important differences in subscale results. For example, Crosson and Bunning (1984) presented a case study of a head injured man with a MQ of 91 who scored nearly perfect on the Visual Reproduction subtest, yet was impaired on many of the verbal components of the WMS, including Logical Memory. Factor analyses

of the performances of other head injured patients have produced similar results. Gronwall and Wrightson (1981) factor analyzed the performances of 71 head injured patients on the WMS subtests, the Paced Auditory Serial Addition Task (PASAT), and the Quick Test. The 3 obtained factors were comprised of the following tests: Factor 1-PASAT and Mental Control, Factor 2-Associate Learning, and Factor 3-Quick Test, Information, and Orientation. The factors were suggested to have respectively tapped attention, concentration, and information processing; learning and memory and; general knowledge, verbal competence, and premorbid ability. Factor analyses by other researchers have similarly produced 3 factors (Erickson & Scott, 1977). Thus the WMS would seem to measure functions other than memory. Moreover, the MQ combines performance on these variegated functions into one score. Despite this, several recent studies (e.g., Alexandre, Colombo, Nertempi, & Benedetti, 1983; Barth, Macciocchi, Giordani, Rimel, Jane, & Boll, 1983) have employed the scale as a measure of memory, per se. Alexandre et al. (1983) used the WMS (as a memory test) as part of a composite measure to relate cognitive outcome to various neuropsychological measures of severity of head injury. Barth et al., (1983) used ill-defined indicators of memory from Wechsler's intelligence scales and the WMS to show that memory deficits added to one's ability to predict Halstead Impairment Index scores in a sample of head injured subjects. This reflects the fact that these investigators were not exclusively tapping memory function,

but a composite of cognitive skills not unlike those more extensively represented in the Halstead Impairment Index.

Another problem with the WMS arises from the lack of internal consistency on some of its component subtests. The utility of the memory span subtest of the WMS may be called into question on the basis that digit span forward and digit span backward measure two different abilities, or are at least of different difficulty levels. For example, Lezak (1979) found that the percentage of head injured patients in her sample scoring within normal limits (i.e., 6 digits) on digits forward, was significantly higher during the third year after head injury than during the first year. On the other hand, no such trend was evident for digits backwards. Despite this and other similar findings (Erickson and Scott, 1977) some recent studies (e.g., Groher, 1977) continue to present digit span as a unitary test score when reporting recovery after head injury.

Perhaps the most telling criticism of the WMS is that it confounds learning with memory (Erickson & Scott, 1977). In other words, as traditionally administered, the WMS does not examine how much of what is learned is retained over time. Rather it requires, for many subtests, only immediate repetition of stimulus materials. As such it is more a measure of learning or short-term memory than long-term memory.

This is not to say that the WMS is of no value whatsoever in the assessment of head injured patients. In terms of measurement

of short-term memory or attention deficits in head injured patients, the WMS as traditionally administered may detect such deficits in performance as compared to matched control subjects. For example, Bennet-Levy (1984) found that severely head injured patients performed significantly worse than age, occupation, and estimated-IQ matched controls on immediate recall of the logical memory subtest. However, when recall was required one hour later the patients not only performed worse than the control subjects, they also forgot a greater percentage of what they had recalled the previous hour. The latter deficit may possibly be considered one of long-term memory, as opposed to an attentional or short-term memory deficit.

It is not especially common, however, that patients with long-term memory deficits show short-term deficits as well. For example, in a recent study (Stuss, Ely, Hugenholtz, La Rochelle, Poirier, & Bell, 1985) it was found that 20 patients with good outcome, as defined by the Glasgow Outcome Scale, performed at a level comparable to well-matched controls on 6 of 7 of the WMS subtests as traditionally administered. However, when the Associates Learning and Logical Memory subtests were administered at a 20-30 minute delay, performance of the patient group was significantly below that of the controls. Thomsen (1981) reported similar results in a case of a severely head injured patient. This patient could immediately recall 17 of 22 elements in a logical

memory test, but could not recall anything from the passage at a one hour delay.

Perhaps the best example of the need for a delayed recall condition with the WMS comes from a study conducted by Groher (1977). This study charted the recovery of 14 patients across 5 monthly testings which commenced shortly after head injury was sustained. At 3 months after injury, an average of 5 of 7 WMS subtests were performed within 1 standard deviation of the mean, based on norms supplied by Wechsler. Despite this near normal "memory" performance on most of the WMS subtests, "poor orientation skills and environmental confusion, characterized by getting lost in the hospital and an inability to remember therapy appointments persisted" (p. 222).

In sum, the WMS as traditionally administered may best be considered a measure of many things, including attention, concentration, short-term memory, and general knowledge. Its usefulness as a measure of long-term memory has been enhanced by inclusion of a delayed recall trial for the Logical Memory and Associate Learning Subtests. However, as Brooks (1972) has stated, impairment of components of the memory process should be pinpointed by a memory measure. The WMS is an inadequate instrument for this purpose. The adaptation of the WMS to include delayed recall trials seems to be an attempt to salvage the instrument and attain some of the goals stated by Brooks and

others (e.g., Schacter & Crovitz, 1977). However, other, newer, measures of memory not only decouple long-term and short-term memory but also provide estimates of one's ability to build associations between items in memory, an emphasis of contemporary cognitive psychology mentioned previously in this paper. Examination of one such memory assessment technique, and its application in terms of the elucidation of the nature of memory deficit after head injury, is now undertaken.

The selective reminding procedure. The selective reminding procedure (Buschke, 1973) is an outgrowth of the traditional free recall memory paradigm. A brief summary of issues associated with free recall techniques helps to provide the rationale for preferential use of the selective reminding technique in the study of memory after head injury.

The traditional list learning approach to memory assessment typically involves the consecutive presentation of 10 or more words to a subject. The subject is then required to recall as many of the words as possible. The same list (or another list of words) is then presented, after which recall is again required. Presentation and recall continue for a prescribed number of trials. According to the structural model of memory words from the beginning and the end of such lists are recalled more frequently than words in the middle because they are assumed to be in long-term and short-term storage, respectively. Words from the

middle of the list are recalled less frequently presumably because they have been displaced from short-term memory and also because their trace has decayed before transfer to long-term storage has been attained (Parker & Serats, 1976).

Four processes are associated with the structural model's account of list learning performance provided above. These processes are encoding, transfer, storage and retrieval. Words are encoded into short-term memory and held there until they can be transferred into long-term memory. They are then stored in long-term memory until finally retrieval or recall of the words is required.

Impaired performance on list-learning measures, according to a structural model can be due to (1) poor encoding into short-term memory, (2) lack of transfer into long-term memory, (3) lack of, or inadequate storage in long-term memory, or (4) difficulty retrieving the word from long-term memory. Impaired performance may also result from some combination of these deficits. Because transfer into, storage in, and retrieval from long-term memory are inevitably confounded with each other (e.g., what appears to be lower storage may in fact be due to ineffective transfer to or ineffective retrieval from long-term storage) it is extremely difficult to demonstrate selective impairment of one of the processes.

Other problems with the structural approach's consideration of impairment on traditional list learning paradigms arise as a



result of the repeated presentation of the same word list (Buschke, 1973). Specifically, since each word is presented on each trial the ability to decouple learning from memory is lost. This is because repeated presentation of all words does not allow the subject to demonstrate that the word can be recalled in the absence of presentation, which would demonstrate that the word is in long-term memory. Rather, items that have been learned are hidden among those that have not yet been learned since all words are presented to the subject on each trial. Furthermore, those words recalled by the subject are in effect practised more than words that are not recalled. Finally, continual presentation of the entire list, in any order, may conflict with the subjective organization of items for subsequent retrieval.

A method of list learning that circumvents many of the problems associated with traditional free recall, and allows for the examination of phenomena heretofore beyond the scope of list learning paradigms is Buschke's (1973) selective reminding technique. The first trial in this technique is identical to that found in traditional list learning. Namely, a list of words is read, after which the subject is urged to recall as many of the words as possible without regard to order. On the second presentation, however, only those words that were not recalled on the previous trial are again presented to the subject. The subject then attempts to recall all of the words in the list, not only those he or she has just been reminded of. The next

presentation, similarly, consists of the reminding of those words not recalled on the previous recall attempt. The subject again then attempts to recall all the words from the list, not only the ones just reminded of. This procedure continues until the subject has recalled all of the words on one or a consecutive series of recall attempts or until a predetermined number of trials has been reached.

Buschke described several scoring parameters that can be used with the selective reminding procedure. Total recall simply refers to the number of words recalled on a particular trial. These words may be recalled from long-term storage or from short-term storage. A word is said to be in long-term storage from the first of two consecutive trials on which it is recalled (i.e., once without being reminded of it). It is assumed to remain in long-term storage from that point onward, regardless of whether or not it is recalled on all subsequent trials. Recall from short-term storage, then, is assumed to occur only before a word has been placed in long-term storage (i.e., before being recalled on two consecutive trials).

A word in long-term storage, in turn, may be recalled consistently, that is, from a given trial until the termination of the test. Alternatively, a word in long-term storage may be recalled inconsistently or randomly, that is, on some trials but not others until termination of the test.

Part of the rationale for considering long-term storage and short-term storage in the terms outlined above is based on reasoning originally presented by structural memory theorists. A word on the selective reminding test may be said to be in long-term storage when it is recalled on consecutive trials because interference associated with recall and selective reminding of other words would normally push a word out of short-term memory altogether. However, since the word is recalled it is reasoned that the word must have been transferred into long-term storage. A second line of evidence in support of deeming a word in long-term memory comes from another memory assessment paradigm proposed by Buschke. In a restricted reminding paradigm the subject is only reminded of words not recalled at all (not just those not recalled on the previous trial, as in selective reminding). Buschke has found that both in normal young adults (Buschke, 1974b) and in a "chronic alcoholic" with disordered memory (Buschke & Fuld, 1974) words recalled on one trial, then not recalled for several trials under conditions of restricted reminding, are almost always spontaneously recalled on later trials. This is strong evidence that a word recalled on consecutive trials in selective reminding is indeed in long-term memory. It must be noted, however, that this evidence from restricted reminding studies also raises the possibility that words designated as recalled from short-term memory (i.e. before recall on two consecutive trials) in selective reminding may

actually be in long-term storage. Thus long-term storage and retrieval scores on the selective reminding test are conservative estimates of these parameters.

The selective reminding technique, however, has several advantages over traditional list learning measures (Buschke, 1973). First, since the selective reminding paradigm urges extended recall and then only reminds of words not recalled on the previous trial, the subject is given the opportunity to show what has been learned and is in long-term memory. This is in contrast to traditional list learning paradigms which present all words on all trials, leading to obfuscation of which items are learned and when. A second advantage of selective reminding is that it better controls for practice of each word by presenting those that the subject has not recalled and not presenting those words the subject has recalled. A third advantage of the selective reminding paradigm is that it minimizes interference with an individual's subjective organization of the words in the list, since only some words are presented on each trial.

Perhaps the most important and useful feature of the selective reminding procedure is the fact that recall from long-term storage is broken down into consistent versus inconsistent recall. In terms of traditional structural theories of memory, inconsistent recall from long-term memory would be due to recall failure or inadequate storage in long-term memory. In view of the fact that recall is inevitably confounded with and

dependent on adequacy of storage, however, Buschke (1974a) instead proposed that inconsistent (i.e., random) long-term memory and consistent long-term memory be viewed as two different stages of learning.

The view of long-term memory in terms of random versus consistent stages of learning begs the question of whether storage or retrieval difficulties are at the heart of recall failure. Rather, each stage of learning "presumably entails storage (of information) appropriate for the kind of retrieval characteristic of that stage of learning" (Buschke, 1974a, p. 726). That these are two distinct stages of learning is supported by the finding that, in normals, there is no gradual increase in the probability of a word's random recall; rather, there is an abrupt shift from random recall to consistent recall (Buschke, 1974c).

Rather than viewing disordered memory as due to encoding, storage or retrieval deficit, then, Buschke proposed that disordered memory performance is caused by the inefficient "random" as opposed to "consistent" learning. Random learning is characterized by a lack of utilization of higher order organizational procedures that chunk items together. Thus a patient who had a disproportionate amount of random as compared to consistent long-term recall would be assumed to have difficulty processing information adequately (Buschke & Fuld, 1974).

In conclusion, the selective reminding technique enables one not only to examine memory function in terms of a traditional short-term versus long-term memory dichotomy, it also allows one to possibly tap into information processing deficiencies. Insofar as information processing is a dominant theme in current memory research, the selective reminding test may hold some promise as a tool in delineating the nature of disordered memory after head injury.

#### Selective Reminding Performance After Head Injury.

A review of studies that examined performance on the selective reminding task, and other list learning paradigms, after closed head injury indicates that several dimensions associated with this issue have been considered. That memory is often impaired after head injury is no longer a contentious issue. Rather, factors such as severity and localization of injury and their effects on memory is now of concern. In recent years, the proposition that different components of memory may be differentially affected has also garnered attention. Finally, the time course of recovery of memory function after head injury is an issue that has been investigated.

This literature review is largely structured in terms of the time course of recovery of memory function after injury. However, the other issues mentioned above cannot be divorced from this. For example, those patients with mild injury tend not to be

followed up as long as those with severe injury. Although the specifics of particular studies vary, this literature review will place special emphasis on (a) severity of injury, (b) localization of injury, (c) differential recovery of various memory components and especially, (d) the time course of recovery of memory function after head injury. A note of caution is in order with regards to comparison of various studies. Different authors may use variations of the selective reminding procedure such that the words (items) on a test and important word parameters such as frequency, meaningfulness, and imagery value may vary across studies. The number of words and the number of trials administered may also vary across studies. Thus it is clear that the various measures used may not be of equal difficulty.

In one of the first studies to examine selective reminding test performance after head injury, Levin & Grossman (1976) compared 10 patients aged 13-18 years to a group of 30 age, sex, and education matched controls. Coma duration was defined as the time during which the patient was unable to exhibit vocal responses or purposeful acts following verbal or somatic stimulation. It ranged from 0 to 14 days whereas injury-test interval ranged from 8 to 79 days.

Total long-term recall performance plotted across trials indicated that there was a monotonic increase in long-term recall and a rapid decrease in short-term recall across trials for controls, but not for patients. Long-term recall was

significantly greater in controls than in patients from trial two onward. In contrast, short-term recall was significantly greater in patients from the fifth trial onward. These results were interpreted to mean that patients had difficulty transferring items from short-term to long-term storage. The ratio of consistent long-term recall to total long-term recall was compared across trials for the two groups. Such a ratio is independent of total long-term recall and thus enables one to compare consistent retrieval in groups that differ in terms of absolute level of long-term recall. This measure of relative retrieval efficiency indicated that on 8 of 12 trials the relative contribution of consistent long-term recall to an already reduced long-term recall was impaired. The authors noted that prolonged coma in general and massive left temporal lobe damage (found in one patient) were related to low proportions of consistent long-term recall, but these relationships were not systematically analyzed.

Although there were few subjects in the study, this pioneering work suggested that head injured patients, shortly after injury, may only have at their disposal and thus rely on short-term rather than long-term recall. It also suggested that even with less long-term retrieval to begin with, head injured patients often show a smaller proportion of consistent long-term retrieval. A major problem with the study, however, is that the large variance in coma duration together with the variable injury-test interval precludes inferences as to the impact of



injury severity and time since injury on the adequacy of memory function.

A study by Levin and Eisenberg (1979) did address the issue of the effects of severity of head injury on memory performance. Twenty-seven closed head injured patients aged 13-18 years were divided into groups based on length of coma: Group I had no or only momentary loss of consciousness, Group II had coma of less than 24 hours, and Group III had coma of more than 24 hours.

Length of coma was defined as the time during which a patient failed to respond verbally or motorically to simple commands. Thirteen of 23 patients had CT scan abnormalities but these were not systematically analyzed in terms of their relation to memory performance. Patients were tested at a median of 22 days after injury but injury-test interval ranged from 1 to 440 days.

Selective reminding results indicated that a significantly smaller proportion of Group I subjects revealed impaired memory performance than the two more seriously injured groups, as defined by performance falling more than two standard deviations below the mean of an age appropriate control group. It was also found that the proportion of patients with impaired memory performance rose as the best verbal response component of the Glasgow Coma Scale (GCS) on admission fell. (The other two components of the GCS were thought to be unreliable since all estimates were based on hospital records.) It was not stated, however, what particular

components of the selective reminding task were impaired in the above analyses.

Results were also presented in terms of the performance of the three injury groups on each of the 12 trials for long-term storage, consistent-long term retrieval, and the ratio of words in long-term storage that were consistently retrieved on each trial. For each of the above three measures the two more severely injured groups performed worse than controls from trial six onward. The mildly injured group in general did not perform at a level much below that of the control subjects.

This study's primary contribution was that it showed that patients suffering different severities of closed head injury may show different levels of impairment on the selective reminding task. A major shortcoming of this study is the wide range in injury-test interval such that one cannot gain an idea of the relationship of time since injury to memory deficits or of the interaction of severity of injury and time since injury on memory impairment. Finally, it may have been beneficial to examine the relationship of mass lesion locus to memory performance.

A study that did control for severity of injury as well as injury-test interval (McLean, Temkin, Dikmen, & Wyler, 1983) helped to quantify the effects of these factors on memory function. McLean and coworkers compared performances of 20 mildly and moderately head injured patients to age, sex, education, and race matched controls on a 10 trial, 10 word version of the

selective reminding task. The patients were divided into groups according to length of post-traumatic amnesia (PTA): 9 had PTA of less than 24 hours and 11 had PTA of more than 24 hours. Patients were tested at three days and one month post-injury; controls were tested only once. Outcome measures used were: total number of words (a) recalled across trials, (b) in long-term storage and (c) consistently recalled. Both immediate and delayed trials of recognition and recall were also administered.

Results at the 3 day testing indicated that the more than 24 hour PTA group performed worse than both control and less than 24 hour PTA groups on all measures except delayed recognition. The latter two groups' performances did not differ on any measure. All impaired performances improved significantly between the 3 day and 1 month testings such that after one month there were no significant differences between the groups on any measure. This study is of some value in that it indicates that moderately to severely injured patients (i.e., with PTA >24 hours) show initial memory problems that may dissipate by one month, whereas those with milder injuries do not show memory deficits, even 3 days post-injury. However, the possibility that a ceiling effect due to limited test difficulty may have produced their findings was not considered by the authors. Other problematic aspects of this study include the authors' failure to consider consistent long-term retrieval in proportion to long-term recall in groups with already

discrepant long-term recall scores and lack of an operational definition of PTA.

Gronwall and Wrightson (1981) reported results somewhat at odds with those presented by McLean et al. (1983). Gronwall and Wrightson compared the performances of 17 head injured patients tested at 24 to 27 days post-injury with 15 unskilled workers and 15 university students of the same age group as the patients. The patients had suffered head injury causing PTA of from 2 to 56 hours. Length of PTA for each patient was estimated by retrospective questioning of the patient for return of memory for consecutive events. No patient had a mass lesion or localizing neurological sign. All subjects were examined on a 12 trial, 12 item selective reminding task, with results presented for each of three blocks of four trials on total recall, long-term storage, and consistent long-term recall in proportion to long-term storage.

Results indicated that controls outperformed the patients on the second and third, but not the first block of trials, in terms of total words recalled. However, patient and control groups did not differ on any of the three blocks of trials with regard to number of words in long-term storage. When consistent long-term recall was considered in proportion to long-term storage, controls outperformed patients on all three blocks of trials. The authors explained these findings in terms of a differential effect of head injury on various components of memory. Length of PTA was found to

consistently correlate with total recall and long-term storage measures, but not consistent retrieval in relation to long-term storage. These results were interpreted to mean that impaired consistent retrieval was present in certain patients independent of length of PTA. It should be noted, however, that patients in the study had a relatively limited range of PTA (i.e., 2 to 56 hours).

These findings of impaired performance on two of three selective reminding measures at approximately one month post-injury are not consistent with the findings of McLean et al. (1983), described previously. The latter authors found that mildly and moderately to severely head injured patients performed at a level comparable to controls at one month. One reason for this discrepancy in findings may be a difference in assessment of PTA duration; Gronwall and Wrightson explicated their measure whereas McLean et al. did not. A second possible reason for the discrepancy in results is that in McLean et al.'s study, patients' performances were compared to extremely well-matched control subjects, that is, friends with similar age, race, education, and sex. In contrast Gronwall and Wrightson used a variegated group of control subjects composed half of university students and half of unskilled workers said only to be in the same age group as patients. McLean et al. suggested that the presence of university students in Gronwall and Wrightson's control group may have unmatched patients and controls. Perhaps the most important

reason for the discrepancy in results is that the tests used were very likely of differing difficulty level. In the first place, the words that composed the selective reminding test very likely differed across studies. Furthermore, Gronwall and Wrightson's test consisted of 12 words rather than 10. This may have removed the ceiling effect, which could have accounted for McLean et al.'s findings.

Levin et al. (1982) also examined selective reminding performance in head injured patients tested soon after injury. Ninety-six such patients were classified into the following groups: Mild Injury (normal CT scan and loss of consciousness no longer than a few minutes), Left Lesion (as evidenced by hematoma or other mass lesion on CT scan), Right Lesion (similarly defined), Bilateral Lesion (evidence of bilateral mass lesion on CT scan), or Diffuse Injury (coma lasting beyond a few minutes and no evidence of mass lesion on CT scan). The patients' median age was 20 years and all patients were tested within six months after injury (median of 23 days), but not before normal orientation had returned or a stable plateau of recovery was reached.

Results showed that the Mild Injury group did not differ from the Right Lesion group in terms of total consistent long-term retrieval, but that the former group performed significantly better on the same measure than did the Left Lesion, Bilateral Lesion, and Diffuse Injury groups. Results for long-term storage were said to be very similar, but were not provided. Further

analyses revealed that left temporal lobe damage was responsible for impaired performance of the Left Lesion group. Specifically, when a group with mass lesion primarily of the left temporal lobe was compared with the remainder of the Left Lesion group, whose lesions did not primarily involve the left temporal lobe, the former group performed significantly worse on consistent long-term retrieval. Left temporal lesion was said to be deleterious in terms of storage as well, but analyses were not provided. Finally, long-term storage and consistent long-term retrieval scores were rated as normal or abnormal, respectively, depending on whether they fell above, or at or below the 4th centile of a control group. It was found that a significantly greater proportion of patients with left temporal damage than left nontemporal damage performed abnormally on long-term storage and/or consistent long-term retrieval. Anomic difficulty was said to not be a factor in these results. Left temporal damage patients did not perform worse than Right Lesion patients, purportedly because many patients in the latter group were more severely injured.

Levin et al. (1982) also tested 36 of these patients at least six months after the initial examination (median of 1 year after injury) to examine the persistence of memory deficits. In 16 of 22 patients with initial retrieval deficit, this deficit was said to have improved by the second testing although no details were provided. Of particular note was the fact that all 4 patients

with focal left temporal lobe damage included in the followup study had improved their retrieval scores from the defective range to within normal limits by followup.

Levin et al. summarized the above two studies by saying that early impairment of long-term memory processes was related to mass lesion of the left temporal lobe or diffuse cerebral swelling. Persistent impairment of long-term memory processes was said to be more strongly related to severity of diffuse cerebral damage as measured by such indicators as acute oculovestibular deficit, persistent coma, and residual ventricular enlargement. It must be cautioned, however, that only analyses indicating the importance of left temporal damage early after injury, but not later, were actually presented. Presentation of other data analyses would have done much to elucidate their report. Finally, the fact that lesion groups were not equated for severity of injury may have confounded results arising from the comparison of these groups.

Subsequent reports, however, have lent credence to the finding that left temporal lobe damage need not be present in order for memory, as measured by the selective reminding task, to be impaired. In a recent study (Levin, Kalisky, Handel, Goldman, Eisenberg, Morrison, & Laufen, 1985), four patients who suffered very severe to extremely severe diffuse closed head injuries, as defined by coma duration (i.e., inability to respond to simple commands) of 11 to 45 days were tested four months, one, two, and five years post-injury respectively. No patient had evidence of a



mass lesion on CT scan. Magnetic resonance imaging (MRI) was conducted for each patient concurrent with neuropsychological testing. The MRI technique was able to detect lesions that the CT scan did not. Neither scan, however, was able to detect focal involvement of the left temporal lobe in any patient. Despite this, both consistent long-term recall on each trial and total consistent long-term recall summed across trials was found to be impaired, as compared to normative data. Furthermore, there was little commonality of lesion sites (other than their diffuse nature) across patients that would facilitate precise localization of the lesion(s) causing memory deficit.

Serial testing of a patient yearly from 1 to 5 years after extremely severe diffuse closed head injury provided similar results (Levin, Handel, Goldman, Eisenberg, & Guinto, 1985). In this case, a 19 year old female who was in coma (i.e., could not obey commands) for approximately 2 months and who did not evidence mass lesion on CT scan was tested on the selective reminding task, among other measures, at yearly intervals. She also underwent MRI at five years post-injury. Despite the fact that consistent long-term recall, as well as immediate and delayed recall were impaired as compared to age norms for testings at each of the five years, with no systematic change across testings, MRI revealed negligible evidence of left temporal lobe involvement. Rather the investigators hypothesized that diffuse, left frontal, and post-central gyrus lesions that were in evidence on MRI were

probably the lesions responsible for memory impairment. One final note that is of interest, in terms of differential recovery of memory functions, is that performance on a four choice recognition trial, in contrast to the other measures, was intact from the second testing onward. This is suggestive evidence that recognition memory recovers to within normal limits within two years after injury whereas presumably more effortful skills do not.

The preceding two studies offer some evidence that left temporal lobe lesions are not necessary for the impairment of memory after severe closed head injury. Rather, in such patients, the common pathology of diffuse damage may be the responsible factor. Fluency or anomic difficulty were claimed to be unrelated to memory performance. Such findings, however, must be replicated with larger patient samples, and uncertainties regarding the interpretation of MRI must be resolved before such evidence can be firmly accepted.

That impairment in memory is found after severe head injury regardless of other injury parameters was supported by Meyers, Levin, Eisenberg, and Gura (1983). These investigators examined 39 severely head injured (i.e., Glasgow Coma Scale score of  $\leq 8$  on admission) patients a median of 11.8 months after injury. Outcome measures presented included retrieval from long-term storage on the selective reminding test and scores on the WAIS. The relationship of these measures to (a) early (within one month of

injury) versus late (more than one month since injury) ventricular enlargement and (b) degree of ventricular enlargement was investigated. No significant group differences on any measure were noted between early, late, and non-ventricular dilated groups. Furthermore, despite the existence of a relationship between magnitude of ventricular enlargement and WAIS scores across all but the early enlargers, no such relationship was found for long-term retrieval scores on the selective reminding task. These findings lend credence to the claim that impairment of memory is common after severe head injury regardless of other pathological factors.

The studies reviewed to this point have generally focused on memory performance within several months after head injury and/or have concentrated on the (lack of a) relationship between locus of mass lesions and memory performance. The next group of studies reviewed examine some of the more chronic effects of head injury on memory function at least one year post injury. Differential effects of head injury on various memory processes are also examined.

Levin, Grossman, Rose, and Teasdale (1979) investigated the relationship between outcome after severe head injury, as measured by the Glasgow Outcome Scale, to neuropsychological functioning, including memory. Each of the 27 patients were severely injured as defined by a Glasgow Coma Scale score of 8 or less on admission. Patients were assigned to good outcome (resumption of

normal life;  $N=10$ ), moderate disability (disabled but independent;  $N=12$ ), or severe disability (dependent for daily support;  $N=5$ ) groups based on Glasgow Outcome Scale ratings. Median coma duration defined by lack of verbal or motor responses to simple verbal commands for the good, moderate, and severe groups were 1, 13, and 17 days respectively. The good outcome group had significantly shorter coma duration than the other two groups, which did not differ. Patients were tested at a median followup of 380 days after injury.

Results showed that the number of items in storage at trials 11 and 12 was significantly greater than at trials 3 and 4 for the good and moderate groups only. This may be interpreted as evidence that the severe outcome group had difficulty placing items into long-term storage. Total long-term storage scores indicated significantly higher storage for the good outcome relative to the severe outcome group only. Proportions of patients with impaired total long-term storage scores, as operationalized by being below the 4th centile of a normative group, were also provided. Only 1/10 of the good outcome group fell below this cutoff whereas 3/12 and 5/5 with moderate and severe outcome, respectively did. It should be noted that neither these nor the ratios of patients with defective storage were statistically analyzed.

This study is of some value insofar as it indicates that memory performance on the selective reminding task is related to

an externally defined outcome measure, the Glasgow Outcome Scale. However, the ill-defined group used for normative purposes as well as the marked heterogeneity in performance within the rather small outcome groups limit inferences that may be drawn. Finally, because the good outcome group only had a median coma duration of one day, despite low Glasgow Coma Scale scores, doubt is cast on whether this group had actually suffered as severe an injury as the other two groups.

Tabaddor, Mattis, and Zazula (1984) examined recovery of memory, language, WAIS IQ, and Purdue Pegboard skills at baseline (mean of 20.3 days), six months, and one year in a group of head injured patients. Patients were divided into moderate (GCS= 9 to 11) and severe outcome groups (GCS  $\leq$  8) and baseline testing was conducted only after a score of 100 was attained on the Mattis Dementia Rating Scale, or at 3 months if such a score was not attained before that time. Patients were divided into focal lesion groups according to the hemisphere (left or right, both, or neither) requiring surgery, although the authors noted that any focal injury was assumed to be in addition to diffuse damage.

A total of 68 patients were tested at baseline on the Mattis-Kovner selective reminding task, which consists of 20 words and 12 trials, with recognition probes after every four trials. Results for all patients at baseline showed that verbal memory, as measured by "number of words correct" (not elaborated on) was more than six standard deviations below normative data. Recognition

memory was assessed by  $d'$ , a measure of the certainty with which a subject can discriminate between test and distractor words (Levin et al., 1982). The  $d'$  parameter was between three and four standard deviations below the normative data. The only significant difference between injury severity groups on the Mattis-Kovner memory test was that the moderately injured group scored significantly better on the recognition component than did the severely injured group. There were no differences between the various lesion groups requiring surgery, although the authors acknowledged that this method of localization of injury was rather crude.

Twenty-five of the original group of 68 patients were tested again at six months and one year post-injury. Although the patients who received multiple assessments scored similarly to the larger group of 68 on the memory measures, demographic information such as severity of injury was not provided for the retested group. Comparison of this group's scores at baseline to those attained at one year revealed that scores on all tests except the memory measures improved significantly. It should be noted, however, that recovery in terms of number of words correctly recalled just missed reaching significance ( $p < .06$ ). Recovery curves for both memory measures, however, indicated progressive recovery up to one year post-injury. Finally, even though as graphically presented memory scores did seem to improve, recall

and recognition scores at one year remained 4 and 2.5 standard deviations below the mean of the supplied norms, respectively.

The value of the Tabaddor et al. study is derived from its systematic assessment of memory at specified intervals after injury. Better specification of the nature of focal lesions as well as further demographic information regarding the normative sample and severity of injury in the retested patients would have added to the value of the study.

Parker and Serats (1976) also serially tested the memory of patients after head injury. One hundred and eight such patients were tested at 1, 3, 6, 9, 12, 18, and 24 months after injury on free recall of lists of 12 simple, but meaningful words. Testing was not conducted, however, after an occasion when memory was said to have returned to normal, as defined by an (unspecified) predetermined cutting score and a recall curve that demonstrated roughly normal primacy and recency effects.

Some of the results of the study are as follows. Recall curves were generally found to be (a) normal (i.e., usual primacy and recency effects with a normal level of performance), (b) of normal shape (i.e., with primacy and recency effects) but with a decreased level of performance, or (c) showing recency effects, indicative of short-term memory only. Patients were divided into groups according to length of post-traumatic disorientation (PTD, which was left undefined): Group 1 had PTD of less than 24 hours, Group 2 had PTD of between 24 hours and 2 weeks, Group 3 had PTD

of between 2 weeks and 1 month, and Group 4 had PTD of more than 1 month. It was reported that there was little relationship between length of coma and extent of memory disorder, neither of which was operationally defined, nor was there a relationship between length of coma and time taken for memory to recover. PTD, however, was found to be significantly related to the severity of memory perturbation, memory recovery and the shape of the memory curves. The two less severely injured groups more often performed in a manner consistent with curve (b), while the two more seriously injured groups more often performed in a manner consistent with curve (c), indicative of heavy dependence on short-term memory only. PTD was also related to eventual return of normal memory function insofar as greater numbers of less severely injured patients eventually regained normal memory function. Finally, it was stated that to the extent that memory did recover to normal it almost inevitably happened during the first year after injury, with less recovery taking place thereafter.

Parker and Serats (1976) utilized a potentially informative design, insofar as multiple testings at specified intervals were carried out and the shapes of curves of free recall performance were utilized. Unfortunately, so many key variables such as PTD, length of coma, and normal memory function were left so ill-defined that the results of their study must be viewed with considerable caution. Even disregarding the lack of definition of key variables, one must be cautious in interpretation of results



because no explicit statistical tests were conducted to examine the reliability of results.

The final two studies to be reviewed here (Shore 1981; Shore & Voelker, 1985) also examined the course of recovery of memory function after head injury. They are of special relevance to the present work in that the same selective reminding measure used by the above authors is used in the present study. In the first of these two studies Shore (1981) examined the course of memory recovery in severely to extremely severely closed head injured adults (coma duration ranging from 2 to 175 days). Forty-five patients were tested twice, 18 were tested three times, and 7 were tested four times during the course of recovery. Median injury-test intervals for the four groups were 141, 366, 549, and 712 days, respectively. Unfortunately, injury-test interval varied so widely within testing groups that there was considerable overlap in injury-test interval between groups. Selective reminding test results were reported in terms of (a) percent correct (i.e., number of times the 12 words were accurately recalled across 10 trials, divided by 120), (b) recognition hits on a 24 item yes-no recognition task that contained the original 12 word list plus 12 distractor items, (c) correct rejections, (d) false positives, and (e) false negatives on the recognition task. Additional measures used were (f) the  $d'$  statistic, which measures the certainty with which a subject can discriminate between test and distractor words and (g) the  $A'$  statistic which

is a measure of degree of caution in response bias. Results showed that on all measures except (c) correct rejections and (d) false positives, performance on the selective reminding test was significantly impaired. Furthermore, on all measures which were significantly impaired at testing one, performance improved significantly by testing two. This trend toward improvement continued to the third test for all measures that showed improvement between the first two testings. It is interesting to note that "improvement" in terms of response bias was from a very cautious to a less cautious bias. Negligible improvement was seen by the ~~fourth~~ testing.

Shore and Voelker (1985) examined 11 subjects who had suffered severe to extremely severe head injury (coma duration of 2 to 42 days) and were tested 6, 12, and 18 months after injury. Results were reported in terms of (a) percent correct (b) the proportion of trials before each word had been recalled at least once (c) the proportion of trials between (b) and trials on which there were no omissions and (d) the proportion of trials after the last omission. Unbiased estimates of encoding and storage were also calculated based on measures (b), (c), and (d). However, the only parameter that showed a consistent trend of improvement across all three testings was percent correct. Had post-hoc testing been conducted it is likely that the improvement would have been accounted for primarily by improvement between the 6 and

12 month testings (from a median of 51% to a median of 68% correct) rather than the 12 to 18 month testings (68% to 70%).

The results of the Shore (1981) and Shore and Voelker (1985) studies are somewhat difficult to compare because all except one scoring parameter was different. Furthermore, the Shore (1981) study had extremely variable injury-test interval ranges whereas those in the Shore and Voelker (1985) study were precisely delineated. Nevertheless, it appears from the two studies that improvement in the percent correct parameter was significant, especially during approximately the first year after injury. In addition, the Shore (1981) study suggests that recognition hits, false negatives, response bias ( $A'$ ) and  $d'$  all improve after severe head injury, but wide variability in injury-test interval across testings in the study makes it difficult to ascertain the time course of these changes.

### Conclusions

Four major dimensions that the preceding studies related memory performance after head injury to were (a) severity of injury, (b) locus of injury, (c) time since injury, and (d) the nature of the memory parameter. Although it is difficult to compare and integrate the findings of different studies, a general summary of the findings in each of the above areas is provided below, in order to suggest a rationale and hypotheses for the present research.

The severity of head injury is most often gauged by measures such as length of coma or post-traumatic amnesia. It is assumed that such measures are correlated with severity of diffuse damage. Problems in reliability of such measures across settings has led to use of the Glasgow Coma Scale to assess severity of head injury. Regardless of the measure used in a particular study, however, tentative conclusions can be drawn about the relationship of injury severity and extent of memory dysfunction. Mild to moderate head injury, as defined by no or only transient loss of consciousness or post-traumatic amnesia of less than one day (Jennett & Teasdale, 1981) has usually been found to have relatively minimal effects on performance on a variety of selective reminding measures (Levin et al., 1982; Levin & Eisenberg, 1979; McLean et al., 1983). As one progresses up the severity scale to moderate to severe head injury, increasing evidence of memory impairment is found. Moderate to severe head injury, as defined by Glasgow Coma Scale scores of 9 to 11 on admission or coma or post-traumatic amnesia of no longer than one week (Jennett & Teasdale, 1981) has been associated with memory impairment in many studies to date (e.g., Levin & Eisenberg, 1979; Tabbador et al., 1984), although exceptions to this rule do exist (e.g., McLean et al., 1983). In the McLean et al. (1983) study, a ceiling effect may have accounted for the results in that a 10 trial, 10 word test was used whereas most researchers (e.g., Levin & Eisenberg, 1979; Gronwall & Wrightson, 1981; Tabbador et al.,

1984) use at least a 12 word selective reminding test. In addition, McLean et al. did actually find impairment on their selective reminding task at 3 days post-injury but not one month. Time since injury, then, may be an important factor in the determination of whether or not memory impairment is found with moderate to severe head injury. As one goes from severe to very severe head injury, however, evidence of memory impairment is often found regardless of the time span since injury. Very severe head injury may be defined by Glasgow Coma Scale scores of 8 or less on admission and/or loss of consciousness or presence of post-traumatic amnesia of more than one week (Jennett & Teasdale, 1981). Studies that have examined memory function in such patients (e.g., Myers et al., 1983; Shore, 1981; Tabaddor et al., 1984) have typically found widespread impairment of many components of selective reminding memory tasks.

The study of memory impairment as related to locus of injury has been complicated by the fact that mass lesions are almost always superimposed on widespread damage found after non-trivial head injury. Some investigators (e.g. Levin et al., 1982, Levin & Grossman, 1979) have reported that focal damage of the left temporal lobe is associated with impairment of function on the selective reminding test during the first few months after injury. Although such damage may be sufficient to impair memory shortly after head injury, it does not appear to be necessary. Many investigators have reported that patients with no focal lesions

(e.g., Gronwall & Wrightson, 1981) or with focal lesions restricted to other areas (e.g., Levin, Handel Eisenberg, & Guinto, 1985; Levin, Kalisky, Handel, Goldman, Eisenberg, Morrison, & Laufen, 1985) also show impaired selective reminding test performance after head injury. Perhaps the safest conclusion to make at this point in time is that both temporal lobe (Levin et al., 1982) and extent of severe, diffuse damage (Tabaddor et al., 1984) may be associated with memory impairment in the first few months after injury. After such time only the severity of diffuse effects seems important in terms of memory dysfunction (Levin et al., 1982).

Three general observations with regard to the relationship between time since injury and memory impairment may be made. First, patients with mild to moderate head injuries, even at only a few days post-injury generally show little impairment (McLean et al., 1983), although test difficulty must also be considered when interpreting such findings. Second, as head injury becomes moderate to severe the time since injury becomes an important factor in the degree to which memory is found to be impaired. Moderately to severely head injured patients may sometimes show impairment on a simple selective reminding test at a few days post-injury that is ameliorated by one month (McLean et al., 1983), although with most measures it is commonly found that impairment persists beyond one month (e.g., Gronwall & Wrightson, 1981; Levin & Eisenberg, 1979; Tabaddor et al., 1984). As injury

becomes severe to very severe, impairment is present long past one month (e.g., Shore 1981; Tabaddor et al., 1984) and improvement, although seeming to continue for some time after injury, may (Shore, 1981) or may not (Tabaddor et al., 1984) be statistically significant. Third, even to the extent that improvement in memory function does occur, a substantial number of severely to very severely injured patients never regain normal performance (Tabaddor et al., 1984), although once again the nature of the memory task must be considered.

With regard to the nature or complexity of memory measures it will be recalled that Buschke and Fuld (1974) suggested that impaired memory is often due to cognitive processing deficits. It was further suggested that stringent measures such as consistent long-term recall could tap into cognitive processing deficits by measuring the degree to which a subject is able to chunk information together to enable subsequent consistent recall. Because of this it may be supposed that consistent long-term recall would be especially affected in patients suffering from memory disorder due to head injury. Perhaps surprisingly, however, most investigators have instead reported widespread impairment on initial post-injury testing with the selective reminding test. Impairment relative to controls or normative data has been reported for: long-term storage (Levin & Eisenberg, 1979; Levin, Grossman, Rose, & Teasdale, 1979; McLean et al, 1983); long-term recall (Levin & Grossman, 1976); consistent

long-term recall (Levin et al., 1982; Levin & Eisenberg, 1979; Levin, Handel, Goldman, Eisenberg, & Guinto, 1985; Levin, Kalisky, Handel, Goldman, Eisenberg, Morrison & Laufen, 1985; McLean et al., 1983); the proportion of consistent long-term recall from long-term storage (Gronwall & Wrightson, 1981; Levin & Eisenberg, 1979); the proportion of long-term recall that is consistent long-term recall (Levin & Grossman, 1976); total words recalled (Tabbador et al., 1984); percent correct (Shore, 1981),  $d'$  (Shore, 1981; Tabbador et al., 1984) and  $A'$  (Shore, 1981). In most of these studies, the impairment has been reported when testing followed within days of injury (e.g., McLean et al., 1983) and/or when injury was moderate to severe (e.g., Gronwall & Wrightson, 1981; McLean et al., 1983) or worse (e.g., Levin, Kalisky, Handel, Goldman, Eisenberg, & Laufen, 1985; Shore, 1981; Tabbador et al., 1984). Only one study found no difference between at least moderately injured head injured patients and controls (Gronwall & Wrightson, 1981) and then only on the long-term storage parameter.

Relatively few studies have reported the results of serial testings with the selective reminding task. Summary scores such as percent correct (Shore, 1981; Shore & Voelker, 1985), or total number of words correct (McLean et al., 1983; Tabbador et al., 1984) have generally been found to improve across testings, although Tabbador et al.'s findings just failed to attain statistical significance. With regard to recognition parameters,



both Tabbaddon et al. (1984) and Shore (1981) reported that the d' parameter improved across testings, although once again

Tabbaddon's findings failed to achieve statistical significance.

Shore (1981) also reported that cautiousness in response bias (A') became significantly attenuated across testings. Levin, Handel,

Goldman, Eisenberg, and Guinto (1985) also reported an improvement on a recognition task in a case study, with 10 of 12 words

correctly recognized at one year post-injury and all 12 words correctly recognized at four yearly testings thereafter. Only

McLean et al. (1983) have reported statistically verified results with regard to improvement in conventional selective

reminding parameters such as consistent long-term recall and long-term storage. On both of these parameters patients with

post-traumatic amnesia of one day or more improved significantly to within normal limits, from testing at three days post-injury

to one month post-injury, although the fact that at least some patients were suffering from post-traumatic amnesia at initial

testing confounds these results. Two studies have reported

improvement from initial to followup testing without accompanying statistical analysis. Levin et al. (1982) reported that 16 of 22

patients had improved retrieval scores on second testing at least six months after initial testing (median of one year

post-injury), although details were not provided. Levin, Handel,

Goldman Eisenberg, and Guinto (1985) reported improved consistent

long-term recall from year one to year two post injury in a patient who suffered head injury resulting in two months coma. However, three subsequent yearly testings showed unsystematic fluctuations in consistent long-term recall performance. The paucity of statistically analyzed serial testing data on conventional selective reminding performance parameters is thus apparent.

Finally, only two studies have explicitly reported outcome as compared to controls or normative data on selective reminding performance at least one year post-injury. Tabbaddor et al. (1984) reported that although performance tended to improve during the first year, total words recalled and the  $d'$  parameter were still four and two standard deviations, respectively, below the mean of normative data at one year post-injury. Levin, Handel, Goldman, Eisenberg, and Guinto (1985) reported that whereas performance on a four choice recognition trial improved to perfect by two years after injury, consistent long-term recall performance remained below one standard deviation of normative data during a five year followup.

### Purpose

Many studies to date have examined the effects of closed head injury on verbal memory function. The majority of these, however, have examined memory function only at one point in time after head injury (e.g., Gronwall & Wrightson, 1981; Levin & Eisenberg, 1979; Levin & Grossman, 1976; Levin, Grossman, Rose, & Teasdale, 1979; Myers et al., 1983). Such studies are valuable insofar as they indicate the extent and nature of memory dysfunction in a given sample. Differences in patient, assessment, and procedural characteristics, however, preclude the possibility of constructing recovery curves from the collective results of such studies.

Other studies have serially assessed verbal memory ability after head injury. Patients with mild to moderate head injury have been serially examined within the first month of injury (e.g., McLean et al., 1983) and those with more severe injuries have been serially examined up to one year post-injury (e.g., Levin et al., 1982; Tabaddor et al., 1984). A few studies have extended serial followup assessment beyond one year (e.g., Parker & Serats, 1976; Shore, 1981; Shore & Voelker, 1985) but these studies either have not used the selective reminding technique (Parker & Serats, 1976) or have not reported findings on many of the widely used selective reminding parameters (Shore, 1981; Shore & Voelker, 1985). The only study that has serially assessed performance on the selective reminding task, has extended beyond

one year, and has reported conventional selective reminding parameter results has been a case study (Levin, Handel, Goldman, Eisenberg, & Guinto, 1985).

The present study intends to examine the factors of time since regaining consciousness, nature of the of memory parameter, and their interactions in a sample of severely to extremely severely head injured patients. Time since regaining consciousness rather than time since injury will be used as a variable because the former does not confound length of unconsciousness with time since injury. The present study goes beyond previous investigations by comparing performance on conventional parameters of the selective reminding and recognition tasks during the first six months after return of consciousness to performance on these parameters after at least one year. Although similar research has not been conducted to date (with the exception of one case study), the results of previous investigations summarized in the conclusions section suggest certain hypotheses that guide the present research.

#### Hypotheses

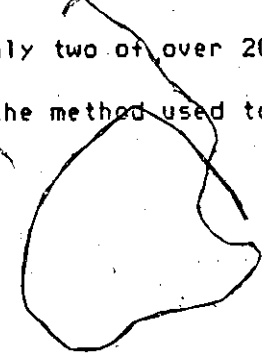
Hypothesis one states that severely to extremely severely head injured patients who are tested during the initial six months post-coma termination will perform worse than matched control subjects on the following measures: (a) total recall, (b) total long-term storage, (c) consistent long-term recall and

(d) consistent long-term recall in proportion to total long-term recall. In addition, it is hypothesized that the patient group will perform worse on (e)  $d'$ , the ability to differentiate between test and distractor items on the recognition trial and (f) a measure of response bias on the recognition trial. Specifically, it is proposed that the patients will have a more conservative response bias (i.e., tend to reject list items rather than affirm distractor items in cases where errors are made). It is also hypothesized that the parameter that best discriminates between patient and control groups will be consistent long-term recall.

Hypothesis two states that performance on all parameters listed under hypothesis one will improve from the first testing to the second. Previous research is lacking with regard to changes in conventional selective reminding parameters over time. However, it is felt that because such measures are inevitably correlated with measures that have been found to improve (e.g., total recall), it is justified to expect improvement on such measures as long-term storage, consistent long-term recall, and total recall.

Hypothesis three states that for a subsample of patients who were tested a third time, improvement would be significantly greater on each measure between testings one and two than between testings two and three. This hypothesis is suggested by the findings of Levin, Handel, Golman, Eisenberg, and Guinto (1985), Shore (1981) and Shore and Voelker (1985).

Hypothesis four states that Average Impairment Rating score at first testing will be a better predictor of memory function at second testing than length of coma will be. The criterion measure of memory function will be that parameter which best discriminates between patient and control groups at testing one. It is predicted that lower Average Impairment Rating (AIR) scores (indicative of less impairment) at initial testing will be associated with better memory performance at second testing. It is acknowledged that there is some bias in this hypothesis in that "percent correct" (i.e., total recall divided by total possible recall) and recognition hits parameters were used in calculation of AIR scores. However, this bias is felt to be minimal because these parameters were only two of over 20 scores used to calculate AIR. (A description of the method used to calculate AIR scores is included in Appendix A.)



## CHAPTER II

### METHODOLOGY

#### Subjects and Procedure

Out of a possible sample of 23 closed head injured patients who were examined at least twice on the selective reminding test as part of a comprehensive neuropsychological exam, 21 patients made up the sample. Two patients, with coma durations of 120 and 180 days, respectively, were excluded in order to minimize the skew of the distribution of coma duration. Sixteen of the 21 patients were tested only twice whereas 5 of the 21 patients were tested three times. The latter five patients comprised the extended followup group. The vast majority of patients were seen at the Rehabilitation Institute of Detroit between 1977 and 1982, although some were tested in private practice. The control subjects were 21 individuals hospitalized for reasons other than injury or dysfunction at the level of the cerebral hemispheres. Descriptive data on control subjects' diagnoses are found in Appendix B. No control subject had a known history of psychiatric disturbance or drug abuse. All control subjects were tested only once.

All patients in the sample suffered closed head injury causing unconsciousness of at least two days, although overall

mean coma duration was 27.6 days ( $SD = 17.0$ , range 2-60). Mean coma duration of the extended followup group was 12.8 days ( $SD = 17.0$ , range 2-42) whereas mean coma duration for the group that was tested only twice was 32.3 days ( $SD = 16.8$ , range 11-60). The difference in coma duration between the latter two groups was significant,  $t(19) = 2.25$ ,  $p < .05$ . Coma was variously defined, because patients were originally admitted to any of several Detroit area hospitals. However, it is proposed that because unconsciousness, which may generally be defined as not being awake and responsive, was of at least 48 hours duration, all patients may be considered to have suffered severe to extremely severe head injuries.

No patient with a missile wound or other penetrating head injury was included in the study. Information with regard to CT scan and other neurological techniques was available for some but not all patients. Because of a lack of consistent information in this regard, such results were not systematically analyzed. Rather, closed head injury resulting in unconsciousness of at least two days duration and lack of significant aphasia were the only defining neurological criteria of the patient sample. It should be noted that some patients in the sample had dysarthria and/or mild language dysfunction.

Because most patients were seen in the context of a rehabilitation setting, the present sample cannot be considered



representative of the population of head injured persons. Rather, individuals referred to the Rehabilitation Institute tended to be those suffering from rather severe disabilities. This fact lends support to the assumption that patients in the present study suffered at least severe injury. In order to rule out premorbid factors as causes of memory impairment, no patient with a prolonged history of alcohol or drug abuse was included; nor was any patient with a history of psychiatric problems severe enough to require hospitalization.

In order to test the hypotheses presented previously, only 21 patients tested within the first six months after return of consciousness and then tested again one year or more after the return of consciousness were included in the present study. Five of the 21 patients were tested a third time and comprised the extended followup group. Time from return of consciousness to each examination for both the overall group and the extended followup group are presented in Table 1. All control subjects were tested only once.

At first testing the patients ranged in age from 14 to 53 years ( $M = 25.6$ ,  $SD = 10.1$ ) and at second testing they ranged in age from 15 to 55 years ( $M = 26.9$ ,  $SD = 10.1$ ). The patient group had completed a mean of 12 years of education ( $SD = 1.9$ , range 8-16) and was comprised of 12 males and 9 females. The extended followup group had a mean age of 23.6 years ( $SD = 4.9$ , range 15-27) at first testing, a mean age of 24.6 years ( $SD = 4.9$ , range

Table 1

Days from Coma Termination to each Examination, for OverallPatient Group and for Extended Followup Group

	<u>N</u>	<u>M</u> Interval	<u>SD</u>	Range
<u>Overall group</u>				
Examination 1	21	108	43	33 to 183
Examination 2	21	515	133	367 to 876
<u>Extended followup group</u>				
Examination 1	5	95	28	66 to 140
Examination 2	5	454	112	376 to 636
Examination 3	5	828	281	508 to 1152

16-28) at second testing, and a mean age of 26.4 years ( $SD = 4.9$ , range 18-29) at third testing. The extended followup group had completed a mean of 12 years of education ( $SD = 1.9$ , range 11-16) and was composed of 4 females and 1 male. At first testing, the only statistically significant subject variable difference between the extended followup group and those patients who were tested only twice was coma duration (see Table 2). However, in addition, it should be noted that even though there was no statistically significant difference in sex ratio, sex ratio did differ considerably. For the only testing at which patients were compared to control subjects (i.e., testing 1) the two groups did not differ on any of sex ratio, age, or years of education (see Table 3).

#### Material

All patients were tested at least twice on a neuropsychological battery that included a free recall test which employed the method of selective reminding. Control subjects were tested on considerably fewer measures, but in all cases the selective reminding procedure was administered.

Selective Reminding Procedure. The selective reminding procedure was introduced by Buschke (1973) to allow "simultaneous analysis of several components of memory and learning in verbal free recall" (p. 543). A second aim was to "illustrate how list learning, as distinct from item learning, may be evaluated in

Table 2

Subject Variable Comparison of Patients Tested Twice (Group 1)  
and Patients Tested Three Times (Group 2)

Variable	Group 1	Group 2	t	p
Sexa	M 11 F 5	M 1 F 4		n.s.
Age	<u>M</u> 26.2 <u>SD</u> 11.4	<u>M</u> 23.6 <u>SD</u> 4.9	0.62	n.s.
Education (years)	<u>M</u> 12.0 <u>SD</u> 1.8	<u>M</u> 12.0 <u>SD</u> 2.6	0.00	n.s.
AIR	<u>M</u> 2.6 <u>SD</u> 0.6	<u>M</u> 2.1 <u>SD</u> 0.2	1.66	n.s.
Coma (days)	<u>M</u> 32.2 <u>SD</u> 16.8	<u>M</u> 12.8 <u>SD</u> 17.0	2.25	.05

$\chi^2(1, N = 21) = 1.97, p > .16$

Table 3

Subject Variable Comparison of Patients and Controls

Variable	Patients		Controls		t	p
Sex <sup>a</sup>	M	12	M	13		n.s.
	F	9	F	8		
Age	<u>M</u>	25.6	<u>M</u>	26.4	0.25	n.s.
	<u>SD</u>	10.1	<u>SD</u>	9.7		
Education (years)	<u>M</u>	12.0	<u>M</u>	12.6	1.00	n.s.
	<u>SD</u>	1.9	<u>SD</u>	2.1		

<sup>a</sup> $\chi^2(1, N = 42) = 1.54, p > .21$

terms of the number of items (or proportion of the list) which is consistently recalled on all subsequent trials" (p. 543).

The selective reminding task used in this study was composed of 12 words of controlled frequency, concrete-abstractness, meaningfulness, and imagery value. The words were selected from the 925 word list of Paivio, Yuille, and Madigan (1968). All words were rated AA in frequency (Thorndike & Lorge, 1944). Six of the words were concrete (bird, girl, door, body, corner, and table) and six of the words were abstract (mind, method, interest, chance, position, and history). Concrete words ranged in concreteness rating from 6.58 to 7.00. Abstract words ranged in concreteness rating from 1.51 to 3.31. Concrete words ranged from 5.12 to 7.96 in meaningfulness rating while abstract words ranged from 5.20 to 6.91 in meaningfulness rating. Concrete words ranged from 6.13 to 6.87 in imagery rating while abstract words ranged from 2.50 to 3.47 in imagery rating (see Appendix C for details).

The following instructions were used:

THIS IS A MEMORY TEST. IT IS MADE UP OF TWELVE WORDS WHICH I WILL READ ALOUD SLOWLY (about one word every two seconds). AFTER I SAY EACH WORD, I WANT YOU TO SAY IT BACK TO ME SO I CAN BE SURE YOU HEARD IT CORRECTLY. AFTER WE HAVE GONE THROUGH ALL TWELVE WORDS WITH YOU REPEATING EACH WORD RIGHT AFTER I SAY IT, I WILL ASK YOU TO RECALL AS MANY OF THE WORDS AS YOU CAN. DO NOT WORRY ABOUT THE ORDER OF THE WORDS OR ABOUT REPEATING YOURSELF. I JUST WANT AS MANY OF THE TWELVE WORDS AS YOU CAN RECALL. WHEN YOU HAVE GIVEN ME ALL THE WORDS YOU CAN, I WILL REREAD ONLY THE WORDS YOU COULD NOT RECALL AND ASK YOU TO TRY FOR ALL TWELVE WORDS AGAIN. I WILL ASSUME YOU ALREADY KNOW THE WORDS YOU COULD REMEMBER, AND ONLY REREAD THE ONES YOU STILL NEED PRACTICE ON. I WILL KEEP DOING THIS, REREADING ONLY THE WORDS YOU MISS, UNTIL YOU GET ALL TWELVE WORDS IN ONE TRY.

Trial one consists of 12 words read aloud by the examiner at a rate of one word every two seconds. Immediately after each word is read, the patient is to repeat it aloud to insure accurate reception, and to insure that the examiner can understand the patient's pronunciation. Any misperception on the patient's part is immediately corrected, repeating with stress the correct word.

Upon completion of reading all 12 words of trial one, the patient recalls all of the words he can remember. A 45 second recall period is allowed and extraneous conversation on the part of either the examiner or the patient is avoided to reduce distraction. As each word is recalled, the examiner places the appropriate number (order of recall) behind the word, that is, if bird is the first word recalled, a "1" would be placed in the 1 (column) 1 (word) matrix (see Figure 1). Any intrusion errors (words not appearing on the list) are immediately and succinctly labelled as incorrect, for example, "There's no boy." These errors are also documented under the appropriate column with the trial number, sequence-in-recall number, and the word itself. For example, if a patient said boy after six correct words on trial one, the documentation appears as follows: 1-7 boy (see Figure 1). The use of the number 7 in no way affects the numbering sequence of correctly recalled words. The next correctly recalled word on trial one would also receive a 7 in the trial-word matrix.

When patients are obviously covertly reviewing the words during recall in an attempt to think of additional words not





already verbalized, they are encouraged to review aloud. Patients frequently think they have recalled a word when they have not, and benefit from reviewing aloud.

When recall is complete (or 45 seconds have passed) trial two is read aloud. Trial two consists of only those words not recalled on trial one. This process (reading those words not recalled on the preceding trial) is repeated for trials three, four and five unless criterion (all 12 words correctly recalled on one trial) is achieved. The test is complete if all 12 words are recalled on a given trial, and is terminated at that point.

If criterion has not been achieved by the end of trial five, the recognition testing is done. This consists of instructing the patient that 24 words will be read aloud and 12 of these words will be from the list. The patient is to respond "yes" or "no" after each word, the "no" response being appropriate for a non-list distractor word. The examiner scores these responses (1 for correct, 0 for incorrect) in the appropriate boxes behind each word. The following instructions are read:

NOW I WILL READ TWENTY-FOUR WORDS AND I JUST WANT YOU TO TELL ME "YES," IF A WORD IS ONE OF THE TWELVE I'VE BEEN READING TO YOU, AND "NO" IF IT IS NOT FROM THE LIST OF TWELVE I'VE BEEN READING.

Following recognition testing, the 12 list words are again read to the patient prior to trial six. This is done to reduce confusion

possibly introduced by the distractor words during recognition testing.

Trial seven is conducted exactly like trial two, that is, only those words missed on trial six are read to the patient on trial seven. This process is repeated until criterion is reached (perfect performance on a trial) or trial nine is completed. Although up to 10 trials are normally administered, because some subjects received only 9 trials, for all subjects only data from 9 trials were utilized in the present study.

The scoring parameters used for the recall part of the test are as follows. Sum recalled refers to the number of words recalled on a trial. Sum recalled is comprised of words considered part of short-term recall and of long-term recall. Words considered part of long-term recall are recalled from long-term storage. A word is said to be in long-term storage from the first of two consecutive trials on which it is recalled (i.e., once without being reminded of it). The word is assumed to remain in long-term storage from that point onward regardless of whether or not it is recalled on all subsequent trials. A word in long-term storage recalled on some but not all subsequent trials is said to be part of random long-term recall (i.e. item learning) whereas words in long-term storage recalled from a given trial until termination of the test are said to be part of consistent long-term recall (i.e., list learning). Finally, a word is

considered to be recalled from short-term storage only before it has entered long-term storage.

Figure 1 is an hypothetical selective reminding protocol that illustrates the parameters just described. The stipled cells indicate words presented before each trial. As column (i.e., trial) one indicates, all words are presented at the outset. As indicated in column two, however, only those words not recalled on trial one were presented (i.e., reminded of). The numbers in the boxes of each column represent the order in which the words were recalled on that particular trial.

The total number of words recalled on each trial is indicated in the recalled row. On trial one, six words were recalled. The heavy underline represents words in long-term storage (i.e., recalled on two consecutive trials). Girl, body, table, chance and history were recalled on both trials one and two (the second time not reminded) and are thus in long-term storage. The item "bird" was recalled on trial one but not trial two and thus was considered to be part of short-term recall. Four of the five words recalled from long-term storage (i.e., girl, table, chance, and history) were recalled consistently on all subsequent trials and were thus considered part of list learning. That these four words were consistently recalled from trial one onward is signified by the black arrows. One of the words recalled from long-term storage (i.e., body) was not recalled on all subsequent

trials and was thus considered part of random long-term recall on trial one.

There are four scoring parameters at the bottom of Figure 1. Trials to criterion is listed as 10 because the patient did not recall all 12 words on any one trial until trial 10. Percent correct (% correct) is simply a summary statistic calculated by summing "Recalled" across trials, then dividing it by 120 (the total recalled if every word was recalled on every trial or the number of cells in the 10 by 12 matrix). Intrusion errors refer to the number of words recalled that were not part of the original list. This parameter is not considered in the present study.

For the recognition trial, the examiner reads the 24 words listed and the subject simply replies yes or no contingent upon whether the subject thought the word was part of the original list of 12 words. As indicated in Figure 1, the subject replied (incorrectly) that tree was included (a false positive) whereas the subject did not think that mind and position were part of the list when they actually were (two false negatives). Two parameters are calculated from recognition trial data: (1)  $d'$ , a measure of an individual's ability to separate list from distractor words and (2) conservative response bias, a measure of an individual's tendency to reject list items rather than affirm distractor items in cases where errors are made. The methods used to calculate  $d'$  and conservative response bias respectively, are outlined in Appendix D.

Psychometric data with regard to the reliability and validity of the selective reminding technique are relatively sparse. A study by Hannay and Levin (1985) found significant ( $p < .05$ ) interclass reliability coefficients for all scoring parameters examined that ranged from .484 to .654, depending on the parameter, on four selective reminding tests composed of 12 unrelated words equated for frequency. These were administered at one week intervals to normal young college students. With regard to validity, Trahan and Larrabee (1983) factor analyzed results from 92 normals aged 18 to 61 on several measures from the Wechsler Memory Scale, the WAIS-R, consistent long-term recall from the selective reminding task, and other measures of memory, verbal intelligence, visuospatial ability, and attention. The consistent long-term recall component of the selective reminding task loaded almost exclusively (along with an expanded paired-associates task from the Wechsler Memory Scale) on a factor labelled verbal memory. It did not load with other measures on factors labelled general cognitive, verbal intellectual, and visual memory ability. With regard to age differences, subjects aged 18 to 39 performed significantly better than those aged 40 to 61 on long-term storage and consistent long-term retrieval scores on the selective reminding test. Undoubtedly, though, further research into the psychometric properties of the selective reminding procedure is required.

## CHAPTER III

### RESULTS

#### Data Analysis

The data were entered onto a computer database and were analyzed with the Statistical Package for the Social Sciences-X subprograms. Because not all patients and controls received both selective reminding and recognition testing at each examination, the number of subjects included in different statistical analyses vary. Results are presented in terms of tests of each hypothesis.

Hypothesis one. Hypothesis one stated that at testing one patients would perform worse than controls on all selective reminding and recognition parameters. In order to test this hypothesis a fixed one-way multivariate analysis of variance using Hotelling's  $T^2$  criterion was performed, with diagnosis (i.e., patient or control) as the independent variable and the following dependent variables: total recall (TR), long-term storage (LTS), consistent long-term recall (CLTR), proportion of long-term recall that is consistent long-term recall (CLTR/LTR),  $d'$  (a measure of the ability to separate list from distractor words on the recognition trial), and conservative response bias on the recognition trial (CRB). It was also stated that consistent long-term recall (CLTR) performance would be the best discriminator of patient and control groups. In order to test

this proposition a direct discriminant function analysis was conducted, with the memory parameters as predictor variables and diagnostic groups as criterion variables.

In order to facilitate comparison of patient and control groups, mean performance of the two groups on each memory variable is presented in Table 4. For descriptive purposes,  $t$  values and associated significance levels are also included. As is evident, the control group outperformed the patient group on all variables. With regard to CRB, the patient group exhibited a more conservative response bias, as indicated by the higher mean CRB value. The results of the one-way MANOVA indicated that the mean vectors of the patient and control groups differed significantly, according to Hotelling's  $T^2$  criterion,  $F(6, 32) = 20.76$ ,  $p < .001$ . It should be noted that the assumption of homogeneity of variance-covariance matrices was violated,  $F(21, 4770) = 7.10$ ,  $p < .001$ . This indicates that significance tests may be too liberal, especially when sample sizes are very unequal (Tabachnick & Fidell, 1983). However, in the present MANOVA analysis there was only a small discrepancy in sample size in that 21 controls and 18 patients were included. Furthermore, inspection of the means and standard deviations of the variables listed in Table 4 suggests that, for all variables except CRB, performance of the control group considerably outstripped that of the patient group.

The second part of hypothesis one predicted that CLTR would be the variable that best discriminated between patient and

Table 4

Performance of Patients and Controls on Memory Variables at  
First Testing

Variable	Patients		Controls		t
LTS	<u>M</u> 32.67	<u>SD</u> 22.19	<u>M</u> 85.38	<u>SD</u> 13.26	9.34**
CLTR	<u>M</u> 11.09	<u>SD</u> 11.65	<u>M</u> 73.61	<u>SD</u> 21.97	11.54**
CLTR/LTR	<u>M</u> 0.33	<u>SD</u> 0.22	<u>M</u> 0.86	<u>SD</u> 0.14	8.21**
TR	<u>M</u> 46.33	<u>SD</u> 17.88	<u>M</u> 91.00	<u>SD</u> 10.31	9.91**
D'	<u>M</u> 1.98	<u>SD</u> 1.83	<u>M</u> 5.39	<u>SD</u> 0.92	7.15**
CRB	<u>M</u> 0.22	<u>SD</u> 0.33	<u>M</u> 0.03	<u>SD</u> 0.09	-2.35*

\*p<.05    \*\*p<.001

(continued on next page)



Table 4 (continued)

LTS: Words in long-term storage, summed across trials.

CLTR: Words consistently recalled after having entered long-term storage, summed across trials.

CLTR/LTR: CLTR divided by total number of words recalled from long-storage, both consistently and inconsistently.

TR: Total number of words recalled (i.e., total short-term recall plus total long-term recall), summed across trials.

D': A measure of the ability to distinguish list from distractor words (values range from -6 to +6, the latter is optimal performance). See Appendix D for further details.

CRB: Conservative response bias. Values range from -1 to +1; the former indicates a totally positive response bias, the latter indicates a totally negative (i.e., conservative) response bias, and a value of 0 indicates no response bias. See Appendix D for details.

control groups. A loading matrix of correlations between predictor variables and the discriminant function, as shown in Table 5, supported this hypothesis. CLTR was found to be a better discriminator of patients and controls than the next best variable, TR. This difference, using Hotelling's  $t$ -test for the difference between two dependent correlation coefficients, was significant  $t(35) = 2.74, p < .01$ . All other variables except CRB were also correlated at least .60 with the discriminant function (see Table 5). Overall, the discriminant function distinguished between patients and controls very well, with a  $\chi^2(6) = 51.71, p < .00001$ . Twenty of 21 controls (95.2%) were correctly classified, as were 19 of 21 patients (90.5%), for an overall classification rate of 92.7%.

As Table 5 shows, several of the memory (predictor) variables were highly correlated. In order to determine which predictor variables would contribute to discriminative power after variance associated with other variables was partialled out, a stepwise discriminant function analysis was conducted. As shown in Table 6, CLTR,  $d'$ , and CLTR/LTR were the only variables that significantly contributed to the stepwise discriminant function.

Hypothesis two. Hypothesis two stated that patients' performance on all memory parameters would improve from the first testing to the second. In the case of CRB, it was hypothesized that response bias would become less conservative. To test this hypothesis, trend analysis was conducted for each variable to

Table 5

Results of Discriminant Function Analysis of Memory Variables

Predictor variable	Correlations of predictor variables with discriminant function	Univariate $F(1,37)$
LTS	.76	82.51
CLTR	.93	124.20
CLTR/LTR	.74	79.28
TR	.83	99.10
D'	.62	56.26
CRB	-.21	6.31
Canonical R	.89	
Eigenvalue	3.89	

Pooled within-group correlations among predictors

Predictor variable	LTS	CLTR	CLTR/LTR	TR	D'	CRB
LTS	1.00	.74	.50	.82	.62	-.13
CLTR		1.00	.68	.77	.48	-.11
CLTR/LTR			1.00	.52	.13	.05
TR				1.00	.68	.01
D'					1.00	.05
CRB						1.00

Table 6

Variables Retained in a Stepwise Discriminant Function Analysis  
of Memory Variables

Predictor variable	Univariate $F$	df
CLTR	124.15	1, 37
D'	63.38	2, 36
CLTR/LTR	43.35	3, 35

determine if there was a linear improvement from testing one to testing two. For each variable, percentage of variance accounted for by the linear trend was also calculated. Results are presented in Table 7. In general, it was found that there was a linear increase in performance from testing one to testing two for the following variables: LTS, CLTR, TR, and d'. There was no linear trend from testing one to testing two for CLTR/LIR and CRB.

Hypothesis three. Hypothesis three stated that for those five patients who were tested three times, improvement would be significantly greater on each memory parameter between testings one and two than between testings two and three. To test this hypothesis, trend analysis was first conducted for each variable, to determine if there was a linear trend between testings one and two. Another trend analysis was then conducted for each variable to determine if there was a quadratic trend across the three testings. For each variable, percentage of variance accounted for by each of the linear and quadratic trends was also calculated. Results are presented in Table 8. In general, it was found that there was neither a linear trend between testings one and two nor a quadratic trend across the three testings for any variable. There was, however, a statistically significant linear trend across the three testings for LTS, CLTR, and TR. Despite these findings, graphic representation of mean performance across testings seemed to indicate a linear improvement in performance between testings one and two and a quadratic trend across all

Table 7

Results of Trend Analyses for Performance on Memory Variables  
from Testing 1 to Testing 2

Variable	Testing 1		Testing 2		df	F	Variance accounted for a
	<u>M</u>	<u>SD</u>	<u>M</u>	<u>SD</u>			
LTS	32.67	22.19	63.43	25.80	1,41	17.16**	30%
CLTR	11.09	11.65	30.57	29.37	1,41	7.97*	17%
CLTR/LTR	0.35	0.25	0.47	0.29	1,41	2.13	5%
TR	46.33	17.88	68.81	18.66	1,41	15.88**	28%
D'	1.97	1.83	4.04	1.35	1,38	16.30**	31%
CRB	0.22	0.33	0.18	0.22	1,38	0.15	.4%

a percentage of variance accounted for by the linear trend.

\*p<.01      \*\*p<.001

Table 8

Results of Trend Analyses for Performance on Memory Variables  
by Extended Followup Group

		LTS	CLTR	CLTR/LTR	TR	D	CRB
Testing 1	<u>M</u>	44.00	19.60	0.46	56.40	3.67	0.17
	<u>SD</u>	26.98	16.68	0.27	22.51	2.08	0.29
Testing 2	<u>M</u>	80.20	57.60	0.69	84.60	4.96	0.15
	<u>SD</u>	23.85	35.88	0.28	19.19	1.49	0.25
Testing 3	<u>M</u>	77.00	63.80	0.77	87.20	5.14	0.08
	<u>SD</u>	19.27	38.21	0.31	17.56	1.18	0.11

Testings 1-2

Linear	<u>F</u>	5.05	4.61	1.90	4.54	1.07	0.01
	<u>df</u>	1,8	1,8	1,8	1,8	1,6	1,6
Variance accounted for		39%	37%	19%	36%	15%	<1%

Testings 1-2-3

Linear	<u>F</u>	4.89*	4.84*	2.99	6.01*	1.54	0.31
	<u>df</u>	1,12	1,12	1,12	1,12	1,10	1,10
Variance accounted for		25%	27%	19%	31%	13%	3%

(continued on next page)

Table 8 (continued)

	LTS	CLTR	CLTR/LTR	TR	D'	CRB
<u>Testings 1-2-3</u>						
Quadratic <u>F</u>	2.33	0.84	0.27	1.38	0.40	0.04
<u>df</u>	1,12	1,12	1,12	1,12	1,10	1,10
Variance accounted for	12%	5%	2%	7%	3%	<1%

\* $p < .05$



three testings for many variables (see Figures 2-5). However, the small sample size, a ceiling effect for CRB, and substantial variation in performance across patients would seem to have prevented such trends from attaining statistical significance. Table 2 displays the scores of each extended followup patient at each testing. As can be seen, depending on the variable, (a) some patients improved across all three testings, (b) some patients improved between first and second testings but not between second and third testings, (c) some patients improved from first to second testing and then showed a slight drop from testings two to three.

Hypothesis four. Hypothesis four stated that Average Impairment Rating (AIR) score at first testing would be a better predictor of memory function at second testing than would length of coma. More specifically, it was hypothesized that lower AIR scores indicative of less impairment at testing one would be associated with better memory function at testing two. The criterion measure of memory function to be used was that which best discriminated between patients and controls at testing one. As discussed under hypothesis one, this measure was CLTR. To test hypothesis four, the correlation between AIR score at first testing and CLTR score at second testing was compared to the correlation between length of coma and CLTR score at second testing. Hotelling's  $t$ -test for the difference between two dependent correlation coefficients was used.

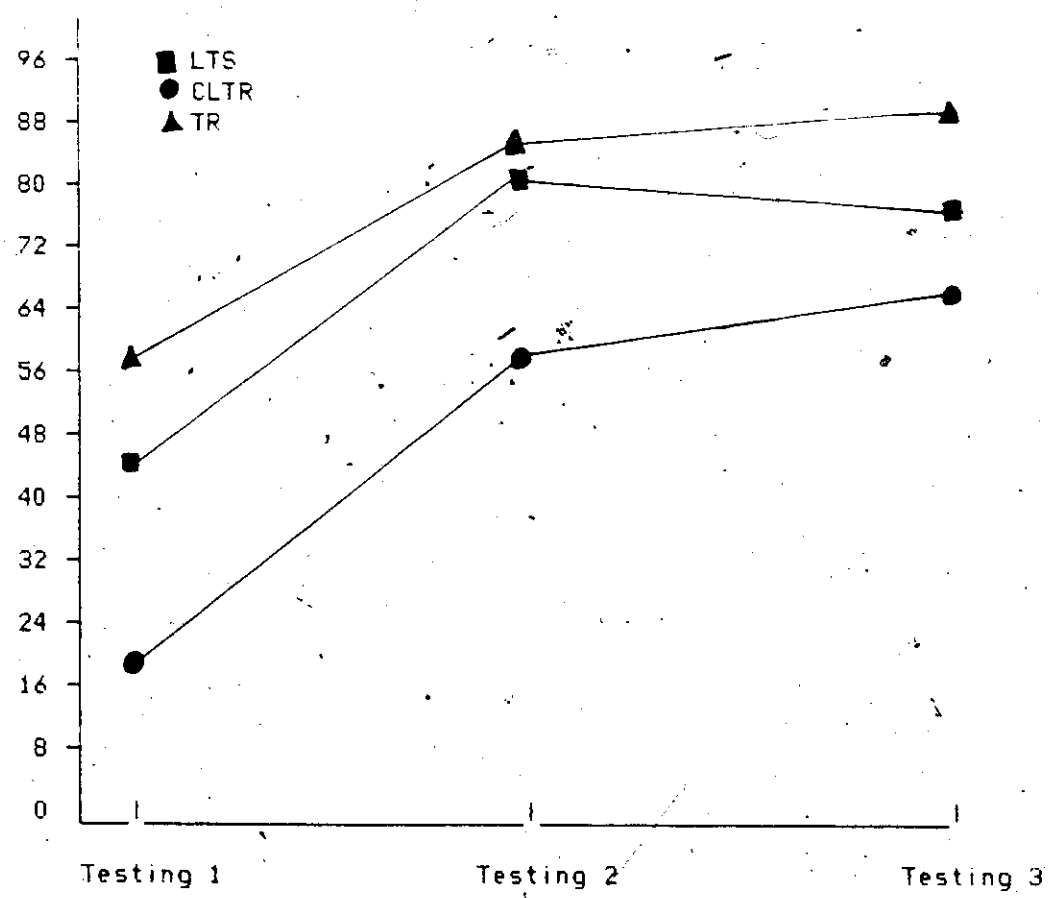


Figure 2. Mean LTS, CLTR, and TR performance for extended followup group at each testing.

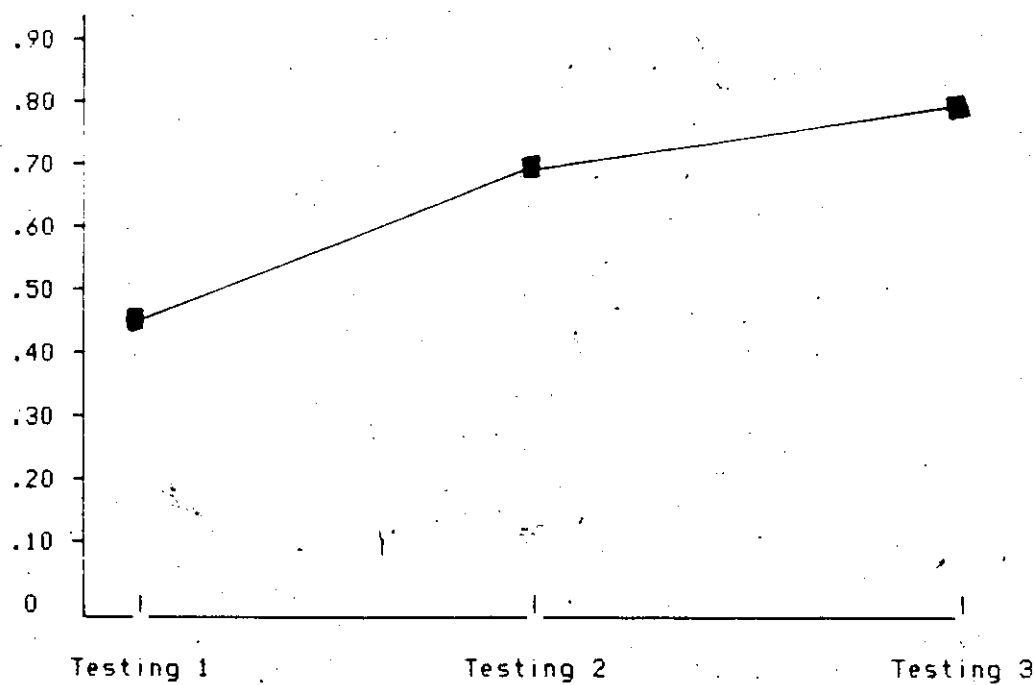


Figure 3. Mean CLTR/LTR performance for extended followup group at each testing.

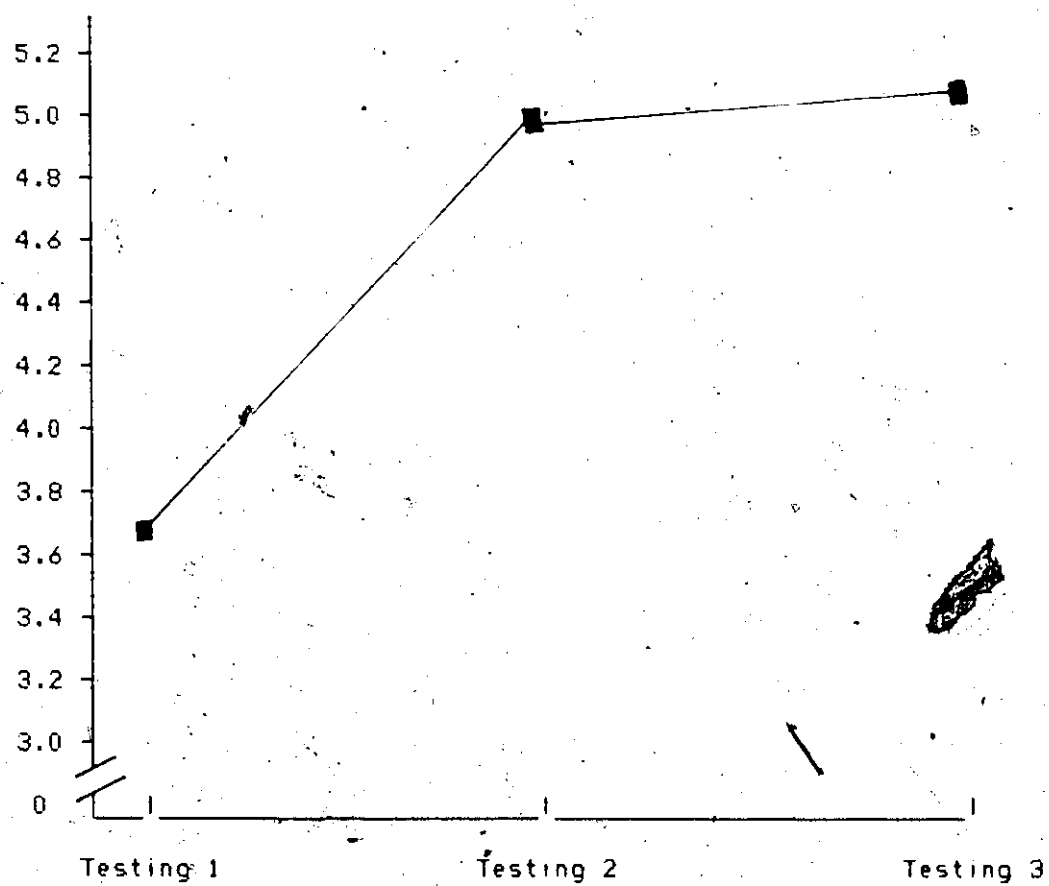


Figure 4. Mean  $d'$  performance for extended followup group at each testing.

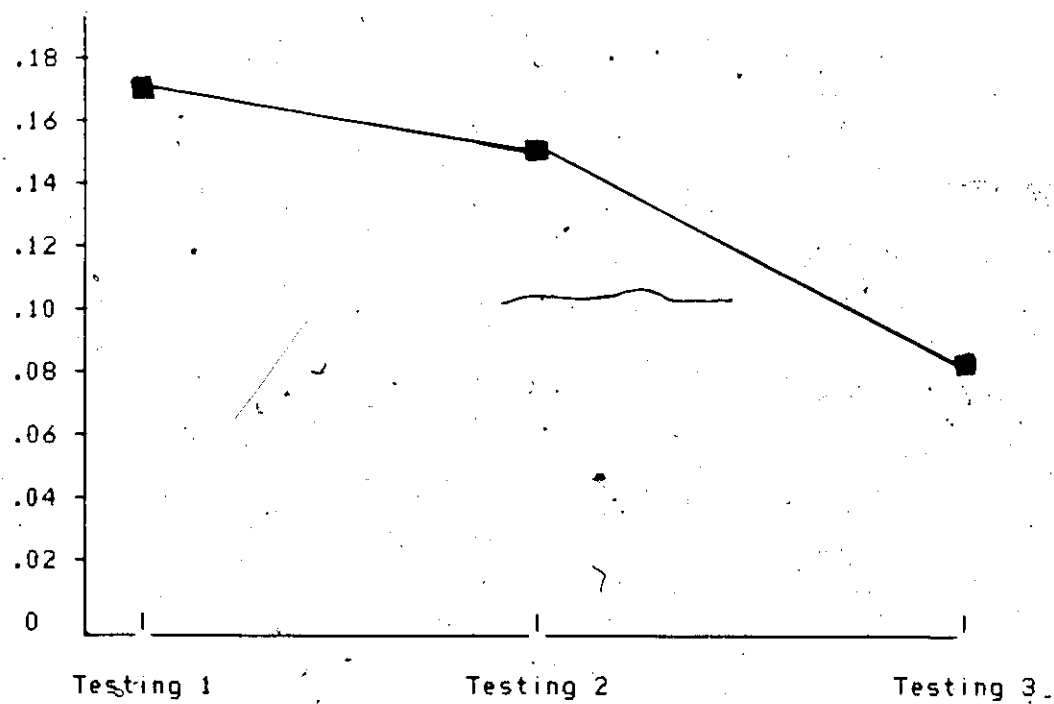


Figure 5. Mean CRB performance for extended followup group at each testing.

Table 9

Memory Variable Raw Scores of each Extended Followup Patient  
at each Testing.

	LTS	CLTR	CLTR/LTR	TR	D'	CRB
<u>Patient 1</u>						
Testing 1	10	1	0.14	44	3.0	0.50
Testing 2	41	9	0.29	55	2.8	0.58
Testing 3	49	14	0.34	61	3.7	0.25
<u>Patient 2</u>						
Testing 1	35	24	0.77	58	0.0	0.00
Testing 2	83	66	0.84	89	4.0	0.17
Testing 3	65	31	0.53	77	4.0	0.17
<u>Patient 3</u>						
Testing 1	81	40	0.56	84	6.0	0.00
Testing 2	104	104	1.00	106	6.0	0.00
Testing 3	87	90	0.98	99	6.0	0.00
<u>Patient 4</u>						
Testing 1	35	4	0.22	26	2.0	0.00
Testing 2	93	71	0.80	94	6.0	0.00
Testing 3	94	94	1.00	100	6.0	0.00
<u>Patient 5</u>						
Testing 1	59	29	0.59	70	0.0	0.00
Testing 2	80	38	0.54	79	6.0	0.00
Testing 3	90	90	1.00	99	6.0	0.00

Hypothesis four was only partially supported. Lower AIR scores at first testing were significantly related to better memory functioning at second testing. However, even though AIR score at first testing was, in rank order terms, more strongly correlated with CLTR at second testing than was length of coma ( $-.56$  vs.  $-.46$ ) this difference was not statistically significant  $t(18) = .67$ , n.s. For descriptive purposes, presented in Table 10 are correlations among coma duration and memory and AIR scores for patients at each testing. As can be seen, AIR score at each testing was generally more highly correlated, than was coma duration, with memory scores.

Table 10

Correlations of Patients' Coma Durations and AIR Scores at each Testing with their Memory Variable Scores at each Testing.

Testing 1	Coma duration	AIR score
LTS	-.38*	-.68***
CLTR	-.39*	-.65***
CLTR/LTR	-.26	-.35
TR	-.31	-.64***
D'	-.34	-.45*
CRB	.08	.00

Testing 2	Coma duration	AIR score
LTS	-.11	-.47*
CLTR	-.46*	-.59***
CLTR/LTR	-.50**	-.60**
TR	-.39*	-.57**
D'	.03	-.17
CRB	.10	.43*

\* $p < .05$ , \*\* $p < .01$ , \*\*\* $p < .001$



## CHAPTER IV

### DISCUSSION

Before the results of this study are discussed, several points with regard to subject and procedural characteristics should be made. First, the patients in the present sample suffered severe to extremely severe closed head injury, as indicated by coma durations of 2 to 60 days. Results are thus not readily generalizable to patients suffering less severe injury. Second, because patients were originally admitted to any of several Detroit area hospitals, reliability of the definition of length of unconsciousness is somewhat uncertain. Third, loci of any focal lesions were not considered due to inconsistent information in this regard. Even though previous research has found little relationship between locus of focal lesion and selective reminding performance several months post-injury, there has been some suggestion that left temporal lobe damage may impair memory performance within the first few months after injury (Levin et al., 1982). Fourth, patients in the present study were tested within six months after the return of consciousness and then again at least one year post-return of consciousness. There was some variability across patients in terms of time to first testing and time between first and second testing. This precludes precise inferences as to recovery span. Fifth, selective reminding tests

vary across studies such that test difficulty may differ from study to study. This prevents a degree of inter-study comparability that would otherwise enhance integration of research findings. Finally, the patients in this study ranged from 14 to 53 years of age at time of first testing. Any possible differences in memory impairment or recovery associated with age may thus be obfuscated in this study.

Discussion of results is broken down into five sections. In the first four sections, results of the tests of each hypothesis are considered. In the fifth section, the primary contributions of this study are summarized and suggestions for future research are made.

#### Hypothesis one

Hypothesis one stated that on all memory parameters, controls would outperform patients who were tested within six months after return of consciousness. Hypothesis one also stated that even though patients' performance on all memory parameters would be impaired, CLTR would be most impaired and thus able to discriminate best between patient and control groups. Both parts of hypothesis one were generally supported.

The finding that patients' initial performance on all selective reminding parameters (i.e., LTS, CLTR, CLTR/LTR, and TR) and recognition (i.e.,  $d'$  and CRB) parameters was impaired is consistent with previous research. Studies that have also

examined severely to extremely severely head injured subjects within approximately six months after injury have reported impairment on the following parameters: CLTR (Levin, Kalisky, Handel, Goldman, Eisenberg, Morrison, & Laufen, 1985), TR (Tabbador et al., 1984), percent correct (Shore, 1981),  $d'$  (Tabbador et al., 1984) and response bias (Shore, 1981). The present study confirms impaired CLTR, TR, percent correct,  $d'$ , and response bias performance in such patients within approximately six months after return of consciousness. It goes beyond previous research by reporting impairment on LTS and CLTR/LTR parameters in such patients within six months of return of consciousness. It may thus be said that impaired memory for words is pervasive, regardless of the parameter used, at least in terms of the injury severity and procedural characteristics of the present study.

Much of the previous research that has examined selective reminding performance after head injury has either grouped patients with vastly different injury severity together (e.g., Gronwall & Wrightson, 1981; Levin & Grossman, 1976) or has not attempted to control for time since injury or return of consciousness (e.g., Levin & Eisenberg, 1979). However, two studies utilized some control over injury severity and injury-test interval, and tested patients with injuries milder than those found in the present sample. McLean et al. (1983) found that patients with generally milder injuries than those included in the present sample performed within normal limits on LTS, CLTR, and TR

by one month post-injury. That McLean et al. only used a 10-word version of the selective reminding procedure may have produced a ceiling effect, accounting for the apparent lack of memory impairment. Levin et al. (1982) reported that patients who suffered no focal lesion and only very brief loss of consciousness outperformed patients with left hemisphere focal lesion, bilateral focal lesion, or diffuse injury on LTS and CLTR.

In summary, only patients who have suffered severe to extremely severe closed head injuries have been shown to exhibit clear and pervasive verbal memory deficits within approximately six months of injury. Due to a variety of methodological inconsistencies and shortcomings in previous research, no definitive statement can be made as to the degree or pervasiveness of impairment on the selective reminding procedure within six months after injury for patients who have suffered mild to moderate closed head injury.

Despite the fact that patients' performance on all memory parameters was initially impaired in the present study, CLTR was the memory parameter found to best discriminate between patients and controls. However, there was a relatively low subject to variable ratio in the present study (i.e., 7:1 whereas 5:1 is an absolute minimum and 20:1 is desirable to ensure stability of results; Tabachnick and Fidell, 1983). Without replication of the present results it is difficult to ascertain the reliability of this finding. Furthermore, variables such as TR, LTS, CLTR/LTR,

and  $d'$  also discriminated between patients and controls, though to a lesser degree. To the extent that the present results are reliable, they would seem to support Buschke's contention that a distinction between consistent long-term recall (CLTR) and random long-term recall (RLTR) is of use in the analysis of disordered memory (Buschke, 1974b; Buschke & Fuld, 1974). Buschke contends that the traditional view of memory as being composed of such separate processes as storage and retrieval may be misleading. Rather, he states that retrieval is probably dependent upon the adequacy of storage. As such, he considers storage and retrieval to be inseparable and prefers to consider memory as measured by the selective reminding paradigm to consist of item and list learning. Item learning (i.e., RLTR) is characterized by a random memory search, utilized only because items are not chunked together or organized adequately in memory. List learning (i.e., CLTR) is characterized by the integration or chunking of items together in memory. Greater use of cognitive processing is required to enable one to employ list learning. To the extent that chunking or integration of related information (i.e., cognitive processing) is impaired, memory is poor. Indirect evidence for the hypothesis of impaired cognitive processing being associated with poor CLTR scores was presented with the results for hypothesis four. AIR score, a measure of the overall adequacy of brain functioning, was significantly correlated with CLTR and other memory variables.

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In summary, performance on all memory parameters was impaired in severely to extremely severely head injured patients who were tested within six months of return of consciousness. CLTR performance was the most impaired memory parameter. To the extent that this finding is reliable, it may be the result of cognitive processing deficits. Subsequent research could further clarify if this is indeed the case.

#### Hypothesis two

Hypothesis two stated that patients' performance on all memory parameters would improve from the first testing to the second. This hypothesis was only partially supported. Whereas LTS,  $d'$ , TR, CLTR improved, CLTR/LTR and CRB did not.

Relatively few studies have reported serial testing with the selective reminding procedure after head injury. Studies that have examined severely head injured patients and reported results of followup from initial testing at or before six months to second testing at approximately one year post-injury generally confirm the present study's findings of improved TR (Shore, 1981; Shore & Voelker, 1985; Tabaddor et al., 1984). With regard to  $d'$ , Shore (1981) reported improvement over the time span outlined above, a finding consistent with the results of the present study. However, Tabaddor et al. (1984) found no significant improvement on the  $d'$  parameter. Procedural differences may account for this discrepancy in results in that the characteristics of the recognition trials were poorly explicated; Tabaddor et al. only

stated that "recognition probes were presented to the patient every 4 trials" (p. 702).

Levin, Handel, Goldman, Eisenberg, and Guinto (1985) reported that a severely head injured woman who was tested at yearly intervals for five years after injury improved to within normal limits between years one and two on four-choice recognition items. This report is somewhat consistent with the findings of the present study where patients improved on the recognition (i.e., signal detection) parameter  $d'$  (although generally not to within normal limits). Levin et al. (1985) also reported that CLTR did not improve systematically across the five yearly testings. Although this finding is not in complete agreement with group data findings of the present study, the finding of Levin et al. is not improbable given the variance found in head injury patients' performance. Shore's (1981) study was the only previous research that examined response bias in the context of a selective reminding paradigm. He also found that severely head injured patients exhibited a conservative (i.e., cautious) response bias. Unlike the present study, he reported that this bias lessened somewhat with time. This discrepancy in results may have been due to Shore's use of the  $A'$  statistic to measure response bias. In pilot work for the present study, it was found that  $A'$  did not properly measure response bias when recognition performance fell outside of a fairly narrow range.

Levin et al. (1982) reported improved "retrieval" in 16 of 22 patients with varying severity of injury who were tested within the first six months after injury and then again a median of one year after injury. Although the results of Levin et al. are generally consistent with those of the present study, Levin et al. did not state which component of retrieval improved, nor whether the improvement was statistically significant. McLean et al. (1983) found that with patients who were generally less severely injured than those of the present sample, TR, LTS, CLTR, and recognition measures all improved significantly between three days and one month post-injury.

In summary, the results of the present and previous research suggests that TR generally improves within approximately the first year post-injury in both severely and less severely injured patients. Results are mixed as to whether or not  $d'$  and other signal detection parameters based on recognition memory performance improve over a similar time frame, although the weight of the evidence suggests that they do. The limited data available also suggest that CLTR generally improves following injury, although once again all findings are not in accord. Only the present study and McLean et al. (1980) have reported that LTS changes over time. These studies suggest that, for both severely and moderately injured individuals, LTS improves during approximately the first year post-injury.



No previous single study has examined concomitant changes in selective reminding performance by severely head injured patients. In the present study, the finding that LTS,  $d'$ , TR, and CLTR all improved between testings one and two is evidence that memory improves across time after severe head injury. That CRB did not change appreciably indicates that patients tend to continue to reject list words as incorrect rather than affirm non-list words as correct. This finding may be interpreted to mean that head injured patients tend not to confabulate or guess by endorsing non-list words as correct. Rather, they consistently adopt a cautious response set, only endorsing words they are sure they remember. It would be of interest to determine whether such a cautious response set is also found with other tasks, or if it is specific to memory tasks.

Of greatest interest is the dissociation between the improvement seen in CLTR performance and the lack of improvement in CLTR/LTR performance. This dissociation indicates that random long-term retrieval (RLTR) increases at a rate sufficient to prevent the CLTR/LTR ratio from improving significantly (since  $LTR = CLTR + RLTR$ ). It will be recalled that RLTR represents sporadic recall of words that are in LTS. Normal individuals exhibit very little RLTR (Buschke, 1974b; Buschke & Fuld, 1974; the present study). Despite this, patients who are recovering from severe head injury exhibit an increasing amount of RLTR with the passage of time. Buschke (1974b) has termed RLTR the result

of item learning, a type of learning in which items are not chunked together or consolidated adequately in memory. Items are not adequately integrated into a network of strong associations when excessive RLTR is evident; rather, the links connecting items are weak. This leads to inconsistent retrieval (i.e., RLTR). Such a conceptualization of memory leads one to the conclusion that, although there is some improvement in the ability to integrate items together (i.e., improved CLTR) after severe head injury, there are also an inordinate number of weak links associating related items in memory.

The diminished ability to link items together in memory is thought to be indicative of cognitive processing deficits (Buschke, 1984). This interpretation is supported by the findings of Mattis and Kovner (1984) who reported that, when they required their brain-damaged patients to employ mnemonic strategies, memory often improved to within normal limits. However, their patients did not spontaneously attempt to use the mnemonic strategies to promote recall of everyday events. Mattis and Kovner concluded that initiating, attentional, and monitoring mechanisms may be at the heart of reported memory deficits. This is consistent with reports that severely head injured patients are often anergic, inattentive, and easily fatigued (Kloze, 1987; Van Zomeren, 1981).

Memory deficits that persist after head injury may not best be conceptualized simply in terms of either storage or retrieval deficits. Rather, Buschke's (1974a) proposal that inconsistent

(i.e., RLTR) and consistent long-term memory (i.e., CLTR) are different stages of learning in the memory process appear to fit the data of this study. Buschke proposed that each of the two stages of learning presumably entail storage appropriate for the kind of retrieval characteristic of that stage of learning. To the extent that severely head injured patients are anergic, inattentive, easily fatigued and do not spontaneously employ adequate mnemonics, memory is characterized by excessive amounts of RLTR.

To summarize, head injury patients appear to recover some ability to utilize the stage of learning most characteristic of normal memory. This is indicated by improved CLTR scores between testings one and two. The patients in this study also came to rely excessively on an inefficient kind of learning, characterized by RLTR. Future studies should test the hypothesis that inordinate amounts of RLTR are indicative of inadequate cognitive processing which is in turn the result of inattentiveness, lack of energy, and a tendency to become fatigued. Preliminary, indirect support for this hypothesis was offered by Klove (1987). He reported that some severely head injured patients who were administered stimulant medication subsequently had improved memory and other cognitive functions.

#### Hypothesis three

Hypothesis three stated that, for those five patients who were tested three times, improvement would be significantly

greater on each memory parameter between testings one and two than between testings two and three. This hypothesis was not supported. The only trends found were linear improvements across the three testings for LTS, CLTR, and TR.

Only two previous studies have reported the results of serial testings that have extended considerably beyond one year post-injury. Shore and Voelker (1985) reported a linear improvement from testings one to three on a percent correct parameter in severely injured patients tested 6, 12, and 18 months post-injury. Performance was 51%, 68%, and 70%, respectively. No analyses were conducted to determine if there was a quadratic trend to the data, although graphic representation of the data suggested that there was. Levin, Handel, Goldman, Eisenberg, and Guinto (1985) reported the case of a severely head injured patient who was tested at 1, 2, 3, 4, and 5 years post-injury. Although performance on a four-choice recognition task improved to within normal limits from year one to two, no systematic change was seen across testings for CLTR.

In conjunction with the present data, the limited research conducted on extended followup with the selective reminding procedure suggests that TR or percent correct may improve past one year post-injury. The data are less conclusive with regard to CLTR and recognition memory improvement over an extended period of time. The present study is the only one presenting data on LTS, CLTR/LTR, and CRB changes more than one year after return of

consciousness. LTR was the only parameter of the above three to show improvement well past one year. Consistent with the results of the overall patient group who were tested over a shorter period of time, the results found with the patients who were tested three times indicated that, whereas CLTR improved, CLTR/LTR did not. This is evidence that the inefficient RLTR as well as the efficient CLTR continues to increase well past one year post-injury. Even though RLTR may be better than no LTR whatsoever, the fact remains that all of the memory recovery indicated by the TR parameter is not recovery of efficient, normal memory processes. With regard to CRB, the lack of a significant change across time is probably due to a ceiling effect and the variability in performance across patients. Such variability was also evident on the other memory parameters, although in some cases this variability was reduced sufficiently to allow statistically significant change to emerge. This does not take away from the fact that variability is usually the rule rather than the exception in studies of head injury patients. Group data such as those presented in this study can only provide general guidelines as to the recovery process; individual cases often will not fit the overall pattern.

#### Hypothesis four

Hypothesis four stated that AIR score at first testing would be a better predictor of memory function at second testing than would length of coma. It also stated that lower AIR scores

(indicative of less impairment) at testing one would be associated with better memory functioning at testing two. This hypothesis was only partially supported. Even though AIR at first testing was, in rank order terms, more strongly related to CLTR score at second testing than was coma duration, this difference was not statistically significant. However, consistent with the second part of hypothesis four, lower AIR scores at testing one were related to better memory functioning at testing two.

No studies to date have attempted to predict followup selective reminding memory performance based on AIR scores obtained soon after injury. In contrast, several studies have attempted to relate injury severity indices such as length of coma, post-traumatic amnesia (PTA) or Glasgow Coma Scale (GCS) scores to memory performance. Coma and PTA duration as well as GCS scores have all generally been found to be inversely related to selective reminding performance both within several months after injury (e.g., Levin et al., 1982; McLean et al., 1983) and in the longer term (e.g., Levin et al., 1982; Levin & Eisenberg, 1979). Some exceptions do exist in that Tabaddor et al. (1984) found that severity of injury as measured by GCS score was related to  $d'$  but not performance within several weeks of injury. Gronwall and Wrightson also found a dissociation, in that PTA duration was related to TR and LTS but not CLTR/LTS in patients tested 24-27 days after injury. However, other studies have not replicated this finding.

It is somewhat surprising that researchers have neglected to compare the predictive validity of behavioral indices of injury severity (e.g., AIR) to more medically based indices (e.g., PTA or coma duration). The present study confirms previous studies in finding an inverse relationship between memory performance and coma duration. It goes beyond previous studies by finding that AIR is also inversely related to later memory performance.

It will be recalled that there was some bias built into the comparison of AIR and coma duration as predictors of memory performance. AIR scores were derived from performances on a variety of neuropsychological parameters including percent correct and recognition hits on the selective reminding procedure. For practical purposes, this does not take away from the fact that AIR score was a statistically significant predictor of later memory performance. It seems reasonable to predict future neuropsychological performance from present neuropsychological performance, rather than from coma duration or some other purported measure of structural damage. Future research should perhaps attempt to delineate a subset of cognitive variables that would further enhance predictive ability.

### Conclusions

In this study it was found that impairment of memory is pervasive across all test parameters after severe closed head injury. Although such a finding is of value in that it replicates much previous research, the primary contribution of the present

study lies elsewhere. First, neuropsychological measures of injury severity could be used more often than is presently the case to predict future outcome on neuropsychological measures. Future research could define a subset of neuropsychological variables that would further enhance predictive ability.

Perhaps the most important contribution of the present study is the finding that, even though efficient learning and memory as measured by CLTR improves after severe head injury, so too does relatively inefficient learning and memory, as measured by RLTR. Concealed within an improved summary score such as TR is an increase in inefficient learning and memory. Thus, summary scores such as TR can create a falsely optimistic prognostic impression and may not correspond well to everyday functioning. Future research should examine whether increased RLTR is associated with improved summary scores on other cognitive measures, that on second look are also in part due to increased use of relatively inefficient processing strategies. For example, on tasks that are not usually timed, use of inefficient processing strategies could enable one to eventually complete the tasks with few errors. However, if the individual requires an inordinate amount of time to complete these and other tasks, the ability to cope with the often time-pressured demands of daily life could be seriously undermined.

Perhaps the inattentive, anergic, and fatigable severely closed head injured patient does not have the resources to utilize



the more demanding and efficient cognitive processing style(s) of non-head injured persons. The administration of stimulant medication to some severely head injured patients has been reported to improve many aspects of cognitive and social functioning (Klove, 1987). The use of the selective reminding procedure and other sensitive instruments would do much to quantify such changes. For example, if it is possible to demonstrate that RLTR is replaced by CLTR after the use of stimulant medication, a step would be taken towards the integration of research in such areas as basic arousal, information processing, and memory. The sensitive, multidimensional selective reminding procedure should be put to such uses in the future.

V

## APPENDIX A

## Method used to Obtain Average Impairment Ratings (AIR)

The AIR for each patient was derived from his or her average level of performance on those variables listed below on which (a) he or she was tested, and (b) at time of testing were being used to calculate the AIR. Performance on each test was initially classified into one of five grades (zero to four). For all variables except those noted as being qualitative, a score of zero was assigned if performance was more than one standard deviation above the mean of a normal control group and a score of one was assigned if performance was within the range of plus or minus one standard deviation of the control group. Performances more than one, two, or three standard deviations below the mean of the control group were assigned scores of two, three, and four, respectively. For those variables noted to be qualitative, a score of zero to four was assigned based on clinical impression. The overall AIR for each patient was then obtained by finding the average of the AIR scores across measures. Even though most patients did not have all of the measures listed included in the calculation of their impairment index, the entire list is presented for the sake of completeness. The complete set of variables, in alphabetical order, were:

1. Apraxia
2. Astereognosis (tactile form recognition)
3. Ataxia (qualitative)
4. Auditory suppressions
5. Babcock-Levy Story Recall
6. Closure Flexibility
7. Closure Speed
8. Digit Symbol
9. Dysgraphesthesia
10. Finger agnosia
11. Finger Tapping (poorest performance, by dominant or nondominant hand)
12. Flags test
13. Grip Strength (poorest performance, by dominant or nondominant hand)
14. Grooved Pegboard (poorest performance, by dominant or nondominant hand)
15. H words
16. Language impairment (qualitative)
17. Money Road Map Test
18. Motor Free Visual Perception Test
19. Orientation, Level of

20. Perceptual Speed
21. Reaction time
22. Seashore Rhythm Test
23. Selective reminding test, percent correct
24. Selective reminding test, recognition hits
25. Speech Sounds Perception Test
26. Static steadiness
27. Symbol Digit
28. Tactile sensitivity
29. Tactile suppressions
30. Tactual Performance Test (TPT) total time
31. TPT memory
32. TPT location
33. Television writing (poorest performance, by dominant or nondominant hand)
34. Trails A
35. Trails B
36. Visual field defects
37. Visual Search
38. Visual suppressions

## APPENDIX B

Control Subject Diagnoses<sup>a</sup>

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Diagnosis	N
Spinal cord injury	12
Polio	3
Amputee	2
Osteogenesis Imperfecta	2
Burn victim	1
Dyskinesia <sup>b</sup>	1
Rheumatoid Arthritis	1
Traumatic eye injury	1

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<sup>a</sup>Number of diagnoses do not add up to 21 because some patients carried more than 1 diagnosis.

<sup>b</sup>Although the dyskinetic individual was motorically impaired, cognitive functioning appeared to be intact.

## APPENDIX C

Imagery, Concreteness, and Meaningfulness  
Values for Each Word<sup>a</sup>

<u>Word</u>	<u>Imagery<sup>b</sup></u>	<u>Concreteness<sup>c</sup></u>	<u>Meaningfulness<sup>d</sup></u>
Bird	6.67	6.96	7.88
Girl	6.87	6.83	5.12
Door	6.60	7.00	7.96
Body	6.40	6.58	5.61
Corner	6.13	6.65	5.67
Table	6.50	7.00	7.60
Mind	3.03	2.60	5.88
Method	2.63	2.20	5.20
Interest	3.13	2.20	5.52
Chance	2.50	1.51	5.61
Position	2.97	3.31	6.24
History	3.47	3.03	6.91

<sup>a</sup>All words are AA in frequency, that is, relatively frequently occurring words occurring more than 50 times per million (Lorge and Thorndike, 1944).

<sup>b</sup>Imagery ratings are on a scale of 1 to 7. Each word was rated as to the ease with which and how quickly it aroused a mental image (Paivio, Yuille, and Madigan, 1968).

<sup>c</sup>Concreteness ratings are on a scale of 1 to 7. A word was rated as more concrete if it referred to an object, material, or person. A word was rated as more abstract if it referred to an abstract concept that could not be experienced by the senses. (Paivio, Yuille, and Madigan, 1968).

<sup>d</sup>Meaningfulness value is the mean number of associations that subjects generated in 30 seconds (Paivio, Yuille, and Madigan, 1968).

## APPENDIX D

Methods Used to Calculate  $d'$  and CRB

In order to calculate  $d'$ , the false alarm rate,  $P(Y|n)$ , and the hit rate,  $P(Y|sn)$ , were first calculated. Then, the  $z$  values corresponding to  $P(Y|n)$  and  $P(Y|sn)$  were obtained from Table 3.1 of Egan (1975). Finally,  $d'$  was obtained by subtracting the  $z$  value of  $P(Y|sn)$  from the  $z$  value of  $P(Y|n)$ . The maximum value obtainable, for perfect performance, was 6. The minimum value obtainable, when the probability of a hit was zero and the probability of a false alarm was one, was -6.

In order to calculate CRB, the false alarm rate was subtracted from the false negative rate. Thus all values fell in the range from -1 through +1. A score of -1 was obtained if there was a totally positive response bias, a score of +1 was obtained if there was a totally negative (i.e., conservative) response bias, and a score of zero was obtained if there was no response bias.

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## VITA AUCTORIS

Chris Paniak was born on February 18, 1963 in Edmonton, Alberta, to Fred and Jean Paniak. In June, 1980 he obtained his high school matriculation from Louis St. Laurent High School in Edmonton. In June 1985 he graduated from the University of Alberta with a Bachelor of Arts (Honors) Degree in Psychology. Since the autumn of 1985 he has been enrolled in the Doctoral program in Human Clinical Neuropsychology at the University of Windsor. He obtained his Master's Degree in the autumn of 1987 from the University of Windsor.

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